POWER PLANT ENGINEERING

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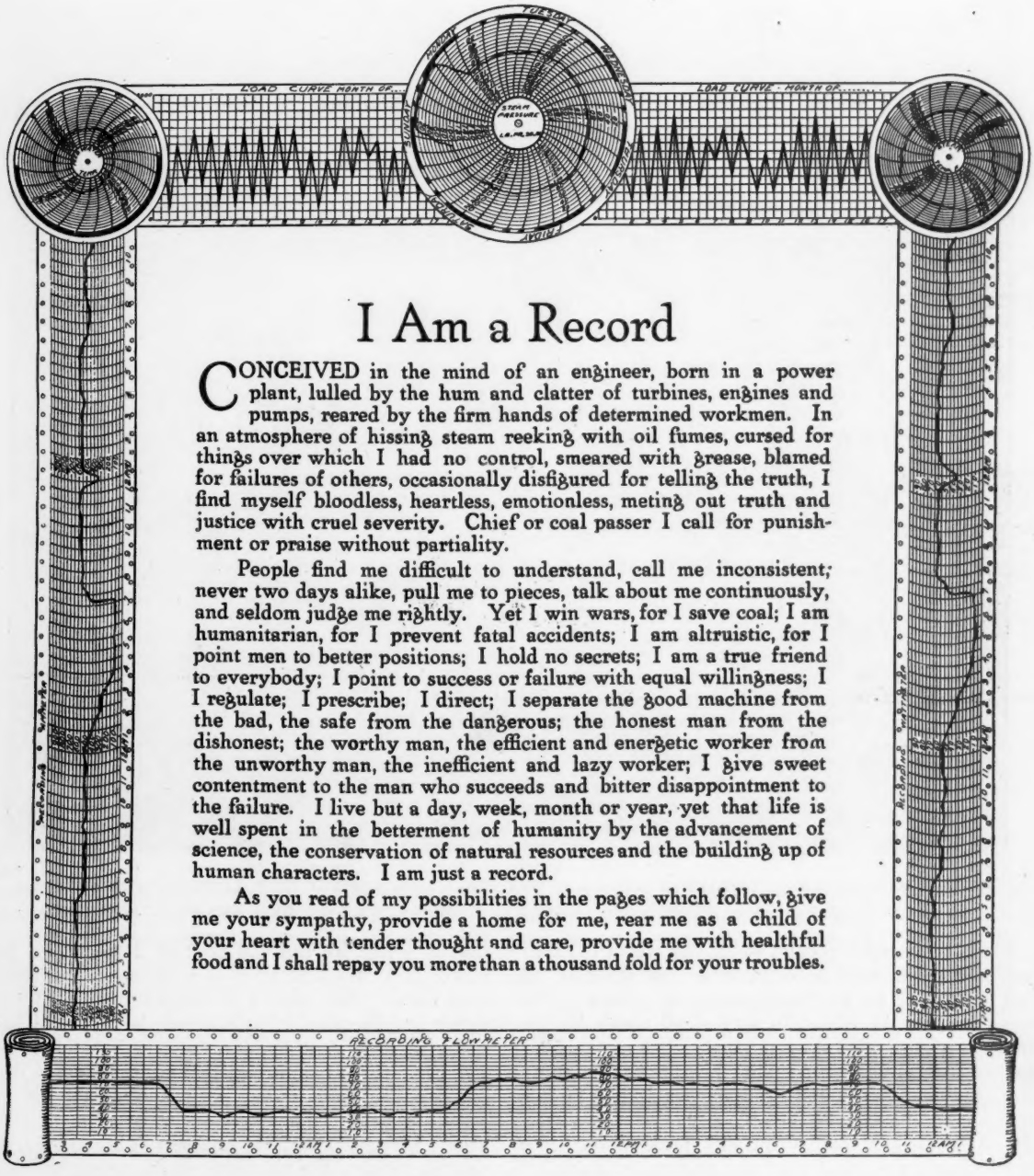


I Am a Record

CONCEIVED in the mind of an engineer, born in a power plant, lulled by the hum and clatter of turbines, engines and pumps, reared by the firm hands of determined workmen. In an atmosphere of hissing steam reeking with oil fumes, cursed for things over which I had no control, smeared with grease, blamed for failures of others, occasionally disfigured for telling the truth, I find myself bloodless, heartless, emotionless, meting out truth and justice with cruel severity. Chief or coal passer I call for punishment or praise without partiality.

People find me difficult to understand, call me inconsistent; never two days alike, pull me to pieces, talk about me continuously, and seldom judge me rightly. Yet I win wars, for I save coal; I am humanitarian, for I prevent fatal accidents; I am altruistic, for I point men to better positions; I hold no secrets; I am a true friend to everybody; I point to success or failure with equal willingness; I I regulate; I prescribe; I direct; I separate the good machine from the bad, the safe from the dangerous; the honest man from the dishonest; the worthy man, the efficient and energetic worker from the unworthy man, the inefficient and lazy worker; I give sweet contentment to the man who succeeds and bitter disappointment to the failure. I live but a day, week, month or year, yet that life is well spent in the betterment of humanity by the advancement of science, the conservation of natural resources and the building up of human characters. I am just a record.

As you read of my possibilities in the pages which follow, give me your sympathy, provide a home for me, rear me as a child of your heart with tender thought and care, provide me with healthful food and I shall repay you more than a thousand fold for your troubles.

Power Plant Records and Analysis

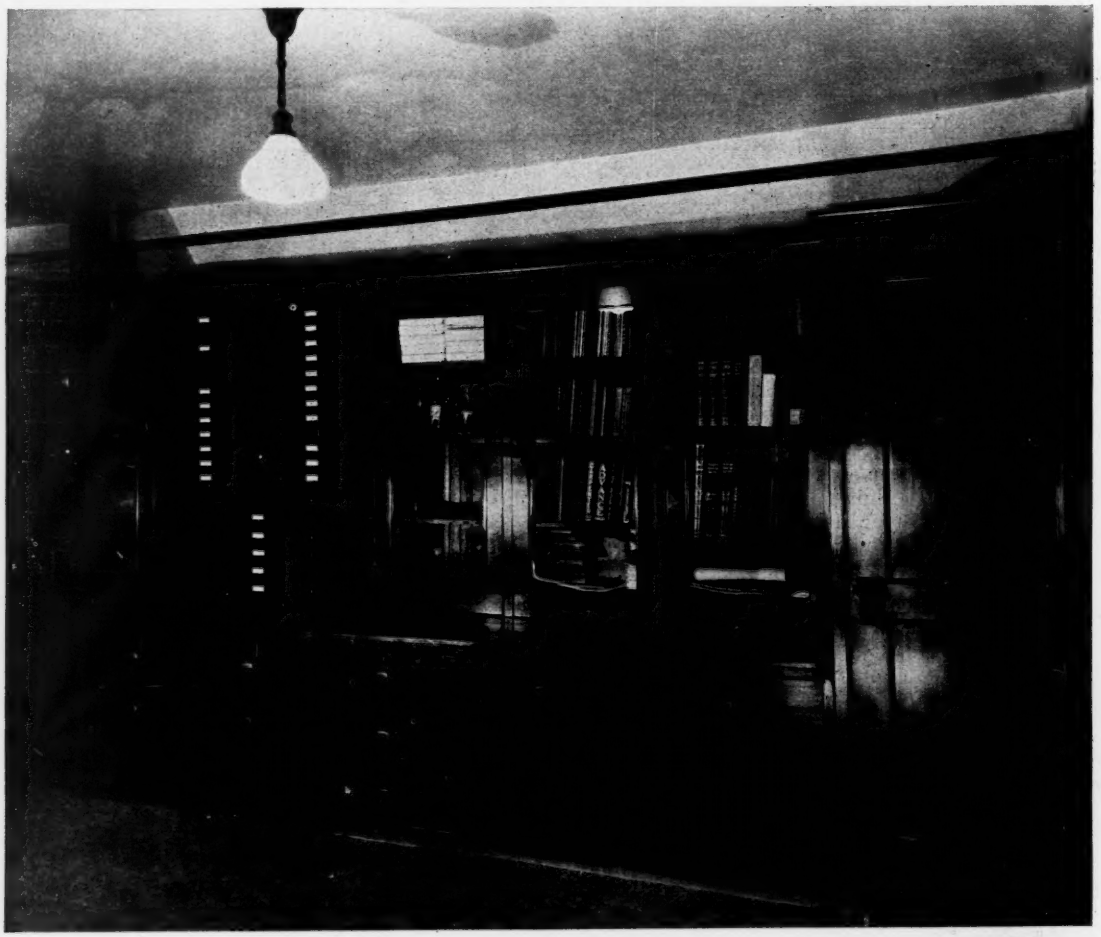
WHERE RECORDS ARE ESSENTIAL; CLASSIFICATION FOR POWER PLANT USE; GENERAL USES TO WHICH THEY CAN BE PUT

PLANNING A SYSTEM of records for a power plant which will meet the needs of the plant yet not be a burden upon those responsible for its keeping is by no means a simple matter, for each item recorded must be of use to the engineer in responsible charge of the plant; if he cannot make use of the item, it may as well be omitted and thus economize in the work of record keeping.

To put any plant on a sound footing, some record of operation is necessary or it will be managed blindly.

Probably the most important and necessary information which can be gained through adequate records comes under one of the following four general heads: first, determination of unit costs; second, determination of efficiencies; third, suggestions for reducing unit costs; fourth, indications of needed improvements.

Wherever one man's work must tie in with another's



CABINET AND REFERENCE LIBRARY IN THE CHIEF ENGINEER'S OFFICE OF THE FIRST NATIONAL BANK BUILDING, CHICAGO. COPIES OF ALL REPORTS AND INSTRUMENT RECORDS ARE KEPT HERE FOR READY REFERENCE

There are many facts and conditions which the engineer of a plant must know in order that he may use good judgment in his management of affairs. This knowledge may be gained in very small plants by personal experience with the equipment; but as the plant becomes larger, one man cannot handle all the equipment, cannot note all the changing conditions as they occur nor can he depend upon his memory for important data to be used in comparison with present conditions. In all plants, the memory of one or two individuals is never safe to depend upon in important matters and permanent records should be kept.

that is where we feel the need of a record, so in the power plant the first need of a record is to determine unit costs. That record is usually demanded by the owner and frequently the engineer is not asked to furnish the data considered necessary, but the information comes from the purchasing and bookkeeping departments. The plant owner must know what his power costs him or he cannot with accuracy estimate what he should charge for it or the products of his factory, which uses the power. For the same reason the engineer should know the cost of all items entering into the cost of power delivered, for only by reducing the cost of these

items separately can he hope to reduce the total cost. So for each plant the engineer will need to record all items entering into the cost of power, from which at definite periods he can determine unit power costs and make comparisons with former records and those of other plants.

The most convenient method of comparing the performance of one machine with that of another for the same purpose is to determine their efficiencies and compare these. This information is not usually required by the owner, but he will be mightily interested if the engineer can show an increase in the efficiency of any machine, for this directly affects his power cost. A rough determination of the efficiencies of the principal machinery can be made from a well planned log sheet; but when a more accurate determination is thought desirable, tests must be run, the data from which form records for comparison with the former results and present day practice.

The reduction of unit costs is the engineer's special work and he should use every means within his power to accomplish that result. In planning his log sheet, he must keep this in mind and record all available data which in any way affected the performance of his machinery, so that he can give intelligent instructions as to the proper conditions to maintain. There is practically no limit to the data which he can collect for this purpose, so he must be guided by the instruments available, the work necessary to keep up the records and the time he has at his disposal to analyze his records.

Obsolescence and inadequacy soon make their appearance in any power plant and it is only by keeping a close tab on each machine or piece of apparatus and making comparisons with the demands of the plant and the performance of the latest types of machine for that purpose that an engineer can safely determine when it is time to recommend a change or addition. His records, if properly planned, will keep him fully informed on this point.

For convenient use, the data needed by the engineer may be divided into three classes, which are necessarily inter-related but collected differently, and kept separately.

First: Permanent statistics include all data of a permanent nature relative to the plant and its equipment.

Second: The operating log contains only such data as change from day to day and is of greatest aid to the engineer in keeping his plant tuned up to the highest pitch.

Third: Test logs are forms specially planned for each machine and filled out during a test for any particular purpose. Their value is of particular importance when important improvements are contemplated.

The planning of each class of records, as well as their uses, will be taken up in separate articles on the pages which follow.

Permanent Statistics

CONVENIENT FORMS FOR RECORDING DATA RELATIVE TO PLANT EQUIPMENT; USE TO WHICH INFORMATION IS PUT

DATA which will show the original condition of the plant and equipment, together with subsequent information which will show at any time thereafter the shape it is in and its probable value, comprise the permanent statistics. A complete list of drawings and specifications showing details of the construction of the buildings and machinery forms a good starter. A record of the corresponding costs is of great value; in fact, the cost of the equipment new is entered on the top line in what is familiarly known as the plant ledger. Each article or unit of the plant is given a separate account in which is shown the first cost, itemized repair and renewal charges, a record of the number of hours run, the amount of depreciation provided for annually, the depreciation reserve fund and the book value of the unit at the end of the year. Therefore, in making up the plant ledger it is customary to divide it up into accounts for the plant buildings and a separate account is opened for each plant unit, such as a boiler, engine, generator, etc. The permanent statistics for each item are then grouped together and placed along with the corresponding accounting data to which they form an important adjunct.

In making up the list of drawings, the catalog number of spare machine parts and their prices should be listed to facilitate re-ordering. Having information of this kind readily accessible is of undoubted advantage in case of a breakdown; a minimum amount of time is lost, as descriptions of the parts required can be ascertained from the records and phoned or wired to the manufacturer of equipment, in order to facilitate immediate replacement. Price data is useful, if kept up to date, and can be checked against figures in the office of the purchasing agent. Information as to prices assists the engineer materially in determining whether an investment for replacement is warranted by large items which show in the charges due to repairs as shown in the plant ledger. This subject of replacement will be discussed at greater length in a later article.

Adjustment of fire losses, also, is greatly facilitated by keeping some form of plant ledger, no matter how generalized the data may be, and it follows that the presentation of such evidence in litigation greatly strengthens the case for the owner and is particularly valuable when the owner has gone to considerable expense to maintain old equipment lost in a fire. Pending settlement of damage claims due to fire or accident, the replacement of equipment is effected with greater rapidity if data is at hand, as the making of measurements in such cases is frequently impossible.

FORMS FOR RECORDING PERMANENT DATA

SIMPLE FORMS on which to record data relative to plant statistics should cover briefly (1) buildings, (2) equipment. Types of these are given herewith.

For small plant purposes or where the engineer has not the facilities at hand to compile more complete records, a few planned along the lines of the group shown in Figs. 1 to 4 will suffice.

In this case, we have laid out a separate permanent

data sheet for the power house building, one each for the boiler room and the engine room equipments, and another for the miscellaneous data, four all told.

The power house data sheet should include items relative to the size and kind of building. This will afford a ready means by which to compute the ground area occupied, useful when it is necessary to pro-rate the land taxes among the various industries occupying a manufacturing site, and for similar purposes. The number of floors, coupled with their superficial area, gives, among other things, data useful when floor preservatives are purchased. The date when built and the

POWER HOUSE DATA

Size of building (length, width, height), ft.....
No. of floors.....
When built.....Name of general contractors.....
Cost new .....$.....
Type of construction: Foundation .....
Floors .....
Walls .....
Insurance rate per $1000.....
Record additions and repairs and when made.....

FIG. 1. POWER HOUSE PERMANENT DATA FOR SMALL PLANT

cost new supply information which must be known before it is possible to compute depreciation and present value. The type of construction, together with the dimensions of the building, afford a basis by which to compute the heating equipment necessary; the type of construction used should, likewise, be an index to the insurance rate.

By providing a place in which to keep a record of the additions and repairs to the building, these items which are frequently charged up by the management to operating cost can be properly accounted for. It also gives a line on the depreciation charges.

BOILER ROOM EQUIPMENT

Make of boilers and type.....
Total No. in plant.....Date installed.....
Steam pressure gage, lb.....Cost new.....
Heating surface, sq. ft. per boiler.....
Grate surface, sq. ft. per boiler.....
Average cross-sectional
Height of stack in ft..... area stack.....
Stoker or grate, kind..... Coal storage, cap.,.....
Coal, kind used..... tons.....
Make of feed pumps.....Date installed.....
Total No. in plant.....Cost new.....
Total rated capacity, gal. per hr.....
Make of feed water heater.....Date installed.....
Type (open or closed).....Cost new.....
Rating .....
Make of economizer.....Date installed.....
Rating .....Cost new.....

FIG. 2. PERMANENT DATA ON BOILER ROOM EQUIPMENT OF SMALL PLANT

Boiler room equipment data should tell the make and number of each kind of boiler in the plant. Every boiler should, preferably, have a plant number, as No. 1, No. 4, No. 10, etc., so that boilers of the same make can be designated without confusion in making tests, keeping boiler repair costs, etc. Gage pressure, relative heating and grate surface and height of stack are points in the design which have to be referred to occasionally. The kind of coal for which the furnace has been designed and the make of grate should also be recorded. Following this corresponding details of the boiler auxiliaries—feed pumps, heaters and economizers—giving their makes and rated capacities should be listed. To complete the boiler room statistics it is necessary that the date of installation of each piece of equipment and its cost new, be placed on record.

Engine room permanent data are compiled as those for the boiler room. The make and type of each engine, turbine, generator and motor should be ascertained and placed in shape for convenient reference. The date of installation and the corresponding cost are also important.

Under miscellaneous data, the engineer of the plant supplying heat, light and elevator service to an office building will collect the statistics pertaining to the elevators, to the water service supply and the water tank capacity. He thus always has a line on the demand

ENGINE ROOM

Make of engine.....Date installed.....
Type.....Size .....Rating.....
Steam pressure.....Cost new.....
Make of generator.....Date installed.....
Type.....Volts, a.c. or d.c.....Rating.....
Cost new.....
Make of motor No. 1.....Date installed.....
Type.....Volts, a.c. or d.c.....Rating.....
Cost new.....
Make of motor No. 2.....etc.....

FIG. 3. ENGINE ROOM DATA FOR PERMANENT RECORD

which may be expected of his service pumps and data for the insurance companies who are interested in knowing what can be expected of the tank in case of fire. If he supplies ice-water or ice to the tenants his refrigerating capacity is of interest. Statistics which will show the kind of heating, the square feet of radiation and the temperature which must be maintained are vital to the engineer who is asked to show how much it costs to keep up the heat in any particular office in the building. Equally important is information relative to the number of lights and the watt-hours consumed. In plants which maintain sprinkler systems, data relative to available tank supply, square feet sprinkled, etc., can be listed as miscellaneous items.

The simple record forms which have been briefly described must be considered only as outlines of what can

MISCELLANEOUS DATA

Elevators, type.....No. .....
Air compressors, make.....Cap., cu. ft.....
Kind of heating.....Sq. ft. of radiation....
Temperature maintained .....
Ice plant, capacity, tons per 24 hr.....
Water tank, sprinkler supply, capacity, gal.....
Water tank, service supply, capacity, gal.....

FIG. 4. PERMANENT DATA ON MISCELLANEOUS EQUIPMENT

be done. Most engineers, will, no doubt, desire to go into more detail with respect to certain features but those given herewith will give them an idea how to proceed in starting the system.

Brief forms for keeping permanent statistics which are somewhat more inclusive than those just illustrated have been grouped together in Figs. 5, 6 and 7. The engine card gives not only the number, maker's name, rating, date of installation and cost, but also the maker's guarantee of performance based on shop test. This permits making a comparison between present performance and that which is guaranteed. Feed-water heater data has been expanded to include the amount of heating surface, the size of tubes or trays and the kind of filtering material, when any is used. Information con-

cerning pumps, traps and meters has been added to the heating system statistics to make these more useful.

On the boiler card we find such additional data as the size of drum, size tubes, thickness of shell, the degree of superheat, etc. The generator has a separate card which contains, among other items, a record of the manufacturer's guarantee of efficiency at various loads. Knowing the percentage of slip (see pump card), the engineer has a good line on the efficiency of his pump as the manufacturer's guarantee of capacity is likewise placed on record, along with suction and discharge pressures.

The elevator card gives not only the number and maker's name and address and the use to which the elevator is put, but also tells its safe capacity in freight or the number of passengers it is designed to carry.

ENGINE CARD

Engine No..... Maker.....
Name & Address

Type..... Size..... Speed..... Rating....hp.

Steam pressure.....

Guarantee of performance or test result. Steam cons. at ¼ load.....

½....., 1....., 1¼....., and 1½ load.....

Cost..... Date installed.....

(Record all extra work and repairs on this engine here and their cost including labor. Each month record total hours run and reduce to days of 24 hr.)

FEED WATER HEATER

F.W.H. No..... Maker.....
Name & Address

Type..... Rating..... Heating surface or tray surface..... Size tubes or trays.....

Filtering material, kind and amount for each charge .....

..... Cost..... Date installed.....

(Repairs - Cleaning - Days in service - Average temperatures for month)

HEATING SYSTEM

Kind..... Sq. ft. radiation.....

Temperature maintained ..... Pressure.....

Equipment..... Pumps.....

Receiver..... Traps.....

B. P. Valve..... Meters.....

(Repairs, additions, lb. condensation, mean temp. for month., hr. exhaust steam, hr. live steam)

FIG. 5. CARD FORMS FOR PERMANENT DATA ON ENGINES, FEED WATER HEATERS AND HEATING SYSTEM

This data is useful in checking with the elevator inspector. The size of cable, if placed on record here, saves considerable annoyance in the case of breakdown and repair and lessens, if it does not render impossible, the making of dangerous mistakes.

A convenient way of keeping this form of record is to place data for each unit or account on one side of a card, the reverse side of which can be used to enter charges for repairs and upkeep and to maintain a record of the hours of service rendered.

Complete Records of Permanent Data

Increasing with the value of the investment should be the completeness of the record pertaining to it. For example, data relative to the plant building is valuable when used in connection with the planning of new buildings and additions. Likewise the amount set aside for a depreciation reserve, if computed properly, will be based on the material and details used in construction.

BOILER CARD

Boiler No..... Maker.....
Name & Address

Type..... Rating..... Heating surface.....

Grate area..... Make or type of furnace.....

Size drum..... Size tubes..... No. tubes.....

Thickness of shell..... Safe steam press.....

Superheat..... Cost..... Date installed.....

(Report all repair and maintenance work with cost. Hours in service during month. Date and result of inspection.)

GENERATOR CARD

Generator No..... Maker.....
Name & Address

Type..... Rating ..... kw. .....Amp.

.....Volts a.c. d.c. ..... phase ..... cycles

.....r.p.m. Efficiency at different loads, ½..... ¾.....

1..... 1¼..... 1½..... Cost..... Date installed.....

(Report all repairs - hours run and kw.-hr. delivered in month.)

PUMP CARD

Pump No..... Used for..... Maker.....

..... Size cyl..... Suction
Name & Address

press..... Discharge press..... Steam press.....

Gal. per stroke at .....% slip ..... Cost.....

Date installed.....

(Record all repairs and hours run or number of strokes.)

FIG. 6. CARD FORMS FOR PERMANENT DATA ON BOILERS, GENERATORS AND PUMPS

Depreciation of wood and galvanized iron buildings, for instance, is much more marked after the lapse of a few years than in the case of stone, brick or concrete.

So in preparing the permanent data record, shown in Fig. 8 of the power plant building itself, details relative to foundation conditions, permissible floor loads,

ELEVATOR CARD

Elevator No..... Maker.....
Name & Address

Use (Freight or Passenger) Type..... Size cables....

..... Diameter..... Length..... Weight, Counter Weight..... Safe load .....lb. or No. people..... Safe speed

..... Trips per mile..... Cost..... Date installed.....

(Repairs - Inspections - Car miles.)

FIG. 7. CARD FORM FOR ELEVATOR DATA

kinds and amounts of building materials used, and names of general and sub-contractors have been included.

If an extension is to be built it is desirable to match the cut stone or terra cotta trim with that in the original building. This is facilitated by our statistics.

Sometimes openings are cut in the walls to let in new service lines or repair leaky pipes, and the enameled brick is so badly damaged that it has to be replaced; our statistics tell us where to get the brick.

Power Plant Building

Dimensions (length, width, height)	Total cost.....
Type of construction (steel, concrete, wood, combination).....	Completed .....
Foundation down to elev.....	Name of general contractor .....
Kind of soil with permissible load	Name of excavating contractor .....
Floor loads permissible:	
Engine room.....	
Basement	
Boiler room.....	
Cu. yd. of concrete and proportion used:	Masonry contractors.....
Foundation.....yd. prop.....	
Walls	
Floors	
Lb. of steel:	
Reinforcing	Structural steel fabricated
Structural	by .....
Common brick .....M.	
Face brick .....M.	Manufactured by.....
Enameled brick .....M.	Manufactured by.....
Cut stone.....cu. ft.	Manufactured by.....
Sash:	From .....Quarry
Wood	Manufactured by.....
Steel	
Terra cotta.....cu. ft.	
Type of roof.....guarantee	Manufactured by.....
Ventilators	Manufactured by.....
Lighting, type	Manufactured by.....
Plumbing and heating.....	Installed by.....
Glazing	Installed by.....
Painting	Installed by.....
Floor preservative.....	Done by.....
Guarantee	Manufactured by.....

FIG. 8. EXTENDED FORM FOR POWER PLANT BUILDING PERMANENT DATA

We want to move in new equipment to replace some which has become obsolete; is our floor built strong enough to permit us to roll the new and heavy turbine across it? Our record shows the permissible floor loads.

Our roof is leaking, let us call in the neighboring roofer to repair it; but wait—surely our roof was laid

Boilers

Make of boiler and type....	Steam pressure gage.....
Date installed.....	Safety valve pressure:
Total number in plant.....	Type .....
Cost of boiler and fittings, each	Number .....
	Cost of foundation and setting, each.....
No. in battery.....	Area of grate.....
Weight of each boiler.....	Type of grate or stoker....
No. of tubes.....	Rated horsepower.....
Diameter of tubes, in.....	Ratio of heating surface to
Length, ft.	grate area.....
Steam space, cu. ft.....	
Water space, cu. ft.....	
Heating surface.....	
Superheating surface.....	
No. of steam drums.....	
Dia. of steam drums, in.....	
Thick. of shell, in.....	
Thick. of head, in.....	
Type of joints.....	Manufacturer's guarantee..
Dia. of steam nozzle, in....	Combined boiler efficiency:
Dia. of safety valves, in....	100% rating.....
Dia. of blowoff, in.....	200% rating.....
Dia. of feed pipe, in.....	300% rating.....

FIG. 9. ITEMS DESIRABLE FOR BOILER STATISTICS

under a guarantee and the building is hardly 10 yr. old, let us look it up and see if our guarantee has expired; our statistics will tell.

We haven't much to paint in our power house, but the contractor who did it last made a good job; he knows what kind of paint to use and how to apply it and here's his name; we would rather not take a chance on anybody else.

Our concrete floors are in first-class shape because the architect knew just what kind of preservative to specify; we'll have to get the same kind for that little office they are building in the engine room for the superintendent. Our permanent statistics, Fig. 8, tells us the brand and the manufacturer's name.

Feed Pumps

Make of feed pump.....	Steam pressure, lb.....
Type of feed pump.....	Back pressure, lb.....
Date installed	No. of valves.....
No. in plant.....	Character of valves.....
	Pounds of water per 24 hr.,
Cost of each.....	average, actual.....
Shop No.	
Dia. of steam cyl.....	Kind of piston packing.....
Dia. of water cyl.....	Size of piston packing.....
Stroke	
Displacement per stroke,	
cu. ft.	Kind of rod packing.....
No. of strokes per min., aver-	Size of rod packing.....
age	Temp. of feed water,
Dia. of suction	deg. F.....
Dia. of discharge	Suction head,
Dia. of steam pipe.....	lb. per sq. in.....
Dia. of exhaust	Discharge head,
Dia. of steam drips.....	lb. per sq. in.....

FIG. 10. CONVENIENT FEED PUMP STATISTICS

The complete boiler record form illustrated in Fig. 9 contains data which is useful in comparing boiler efficiencies and also is a fund of information when figures are needed on which to base boiler performance in running a test. By keeping a permanent record of the principal dimensions of steam nozzles, safety valves, blowoffs, etc., repair parts can be ordered with less liability of the creeping in of errors. Valuable, as a means of checking against efficiency developed during a test, is the record of the manufacturer's guarantee of efficiency under various ratings as compared with the normal boiler horsepower.

Economizers

Make of economizers.....	No. of tubes in each.....
	Length of tubes, ft.....
No. of economizers.....	Heating surface per sq. ft. boiler heating surface, sq. ft. .....
Date installed	Heating surface per boiler horsepower (34.5 lb. water per hr.) rated capacity, sq. ft. .....
Cost of economizers, each...	Economizer material.....
	Horsepower of motor.....

Manufacturer's Guarantee for Each Unit of Economizer

Feed Water Lbs. per Hr.	Temperature Leaving Economizer When Entering at 180 Deg. F.	Gas Temperature Entering, Deg. F.	Gas Temperature Leaving, Deg. F.	Gas Temperature, Difference, Deg. F.

FIG. 11. DATA AND GUARANTEES ON ECONOMIZERS DESIRABLE FOR STATISTICS

Complete feed pump statistics, Fig. 10, should show not only the make and type, whether reciprocating, centrifugal or rotary, but also contain data relative to the diameters of the main parts, such as the steam cylinder, water cylinder, suction and discharge openings, etc. The average steam pressure which is used in operating the pump, its normal pumpage per 24 hr. and the average temperature of the feed water, together with the suction and discharge heads, are vital pump statistics. Here,

furthermore, is the logical place to record the kind and size of piston and rod packing.

In Fig. 11 we have endeavored to show all the vital permanent statistics pertaining to the economizer. Sup-

Chimneys

No.	Amounts of materials used..
Built by.....	Common bricks, No. of...M.
Date built.....	Fire brick, No. of.....M.
Kind (steel, brick, concrete)	By whom manufactured....
Height above grate, ft.....	Yards concrete.....
Diameter at breeching.....	Reinforcing steel.....
Size of breeching.....	Sheet steel.....
Diameter at top.....	Cost of foundation.....
Boilers per chimney.....	
Stack area per 1000 sq. ft. of boiler heating surface .....sq. ft.	

FIG. 12. CHIMNEY DIMENSIONS, MATERIAL, ETC., FOR PLANT STATISTIICS

plementing records which will show the number of tubes, their length and the kind of metal in them and the number of square feet of heating surface per square foot of boiler heating surface and per boiler horse-

Turbines

Turbine No.....1, 2, 3, etc.	Performance Guarantees
Make of turbine.....	Operating condition:
Cost of turbine.....	Lb. press. abs.....
Capacity.....kw. at.....% power factor	Deg. F. superheat.....
	In. vac. condenser.....
Speed, r.p.m.....	In. barometer.....
Operating pressure.....	Net Kw. Load
Operating superheat, deg. F.	of Generator
Exciters, No..... Capacity	Lb. of Steam
each, kw.	Per Kw.-Hr.
Types	For different pressures and
Manufacturer	deg. above or below normal.
Main unit cap. per kw. cap.	temperatures following
of exciters installed, kw..	factors to be used: ....%
Cost of foundation, each....	for each 15 lb. press. for
Heaviest piece to be lifted	range of 25 lb. above or
by crane.....tons	below normal.

FIG. 13. USEFUL STEAM TURBINE DATA FOR PERMANENT RECORDS

power, we include the manufacturer's guarantee showing how much each unit of the economizer will raise the temperature of different volumes of feed water with flue gases of various temperatures.

Condensers

Make of condenser.....	Total tube surface per condenser, sq. ft.....
Date installed.....	Tube area per kw. turbine capacity served by condenser, sq. ft.....
Cost of condenser.....	
Weight of condenser....tons	
Weight of cooling water.... .....tons	Cap. lb. steam per hr. at.... in. vac. and cooling water at .... deg. F.
Circulating pump, cap. each gal. per min.....	Steam condensed per sq. ft. of surface, lb.....
Builder	Cost of foundation, each....
Type	Cross-sectional area, each intake and each discharge tunnel for each unit, sq. ft.
Dia. of discharge pipe, in...	
Circ. water, pumping cap. per lb. of steam condensed at consumption of.....lbs. per kw.-hr. Lbs.....	Intake, tunnel, area per 1000 gal. per min.....
Cooling water per lb. of steam, lb.....	Circulating-water pumping cap., per sq. ft.....
Dry vacuum pump, type....	Screens at circulating water intake, type.....
Hot well pump, type.....	
Hot well pump, size in.....	Manufacturers guarantee:
Hot well pump, builder.....	With....gal. 70 deg. cir. water, vacuum in condenser.....in.
Tubes, No....., dia. ....., length.....	

FIG. 14. FORM FOR PERMANENT DATA ON CONDENSERS

Under the heading of "Chimneys" we find, in Fig. 12, pertinent data which gives us about all we can expect to make use of in connection with this part of the plant. Besides the details of size—height, diameters at various points and the stack area relative to boiler heating surface—it has been considered advisable to provide a place for a record of the materials used in the building of the stacks.

Turbine data covering make, costs, capacity, operating conditions and performance guaranteees are outlined in detail in the form illustrated in Fig. 13. The usual data pertaining to make, date of installation and costs are followed by the rated capacity, speed, operating

Generators

Make of generator.....	Amperes per terminal.....
Type of generator.....	Frequency, cycles.....
Date installed.....	Type of armature winding..
Cost of.....	Speed, r.p.m.....
Capacity, rated at.....%	No. field poles.....
power factor.....kw.	Exciter voltage.....
Voltage	Efficiency guarantees.....

FIG. 15. DESIRABLE GENERATOR STATISTICS

pressure and operating superheat and the principal statistics relative to the exciters. As a check on what is expected of the crane—sometimes one is not provided for in the original construction—the maximum weight to be lifted is also placed on record. The manufacturer's guarantee of what the turbines will do under stated operating conditions relative to pressure, superheat, vacuum in condenser and barometric pressure, shows the pounds of steam per kilowatt-hour required with various loads on the generator and the correction factors to be used with other operating conditions.

Building (Heating, Lighting and Miscellaneous)

Type of building.....	Date service installed.....
No. of floors.....	Area of ground plan..sq. ft.
No. of offices.....	Height of building.....ft.
Total floor space.....sq. ft.	Vol. of bldg., cu. ft.....
Sq. ft. of sides exposed.....	Percentage of exposed walls
Percentage of exposed walls:	glass .....
Wood	Kind of heating.....
Brick	Sq. ft. of radiation.....
Terra cotta.....	Temp. maintained.....
Concrete	
Steel	

Percentage of Building Lighted .....

Lights	Arc	Carbon	Tungsten	Nitrogen filled
Kind of.....				
Watts				
Total watts....				

Elevators, type.....No. .....
Elevators, capacity, each.....lbs.
Air compressors, capacity.....cu. ft.
Compressed air consumption, maximum per 24 hr.....cu. ft.
Ice plant, capacity per 24 hr.....tons
Ice consumed, maximum per 24 hr.....tons
Hot water consumption, maximum per 24 hr.....gal.
Water consumption for miscell. purposes, max. per 24 hr.....gal.
Water tank, service supply, capacity.....gal.
Fire pump, size ... by ... by .... in. pressure .... lb. per sq. in.

FIG. 16. FORM FOR MISCELLANEOUS DATA OF PERMANENT NATURE

Figure 14 is a typical form used to keep a record of condenser statistics. Space is provided for entering data pertaining to the circulating water pumps, the dry-vacuum pump and the hot well pump as respects their type, size, and capacities and the size and capacity of the intake and discharge tunnels for the circulating water. Besides this information, the usual statistics relative to the number and diameter of condenser tubes, the square feet of the tube surface per condenser and per kilowatt turbine capacity, the capacity in pounds of steam per hour at a given vacuum with cooling water of a given temperature, and the amount of steam

condensed per square foot of surface, are also compiled. Place is also provided for the manufacturer's guarantee of performance.

A dozen or so items will pretty well cover the useful data under the subject of generators, Fig. 15. The electrical statistics will comprise: voltage, amperes per terminal, frequency, speed—r.p.m., number of field poles, etc. Besides these we should have the rated capacity at a certain per cent power factor and the maker's efficiency guarantees.

For the use of engineers who supply light and heat to office and mill buildings we have compiled the statistics sheet shown in Fig. 16. The upper part of this record is devoted to data which is highly essential in determining the sufficiency and efficiency of the heating system: the floor areas, amount of total exposure, and percentage of exposed surface of glass and of the various building materials used in walls, and the square feet of radiation required.

The next section covers the subject of lighting. Here are given the numbers of lights of each kind and the corresponding wattages.

Following this comes the elevator record; and statistics pertaining to air compressors, ice plant, hot water consumption, water tank and fire pump complete the list.

All of the permanent statistics which we have just described and illustrated are used from time to time in conjunction with the operating records of costs. It is not the uncommon thing to find that fixed charges of a plant run as high as 30 per cent of the total yearly cost of power. Although it is relatively more difficult to reduce the fixed charges than it is to reduce the various charges incident to cost of fuel, labor, etc., it is well to remember that once a fixed charge has been reduced it stays "put." Therefore all statistics which bear on the subject of fixed charges should be as complete as the facilities for keeping them permit.

Planning Records of Cost Data

Necessary Data, Means and Systems for Collection; Practical Forms

SOME form of power plant report or log sheet, whether simple or complex, is the connecting link between the manager's office and the power plant. It enables the progressive manager or superintendent to lay his finger on weak spots in the power-generating equipment and institute investigations to remedy existing conditions; it permits wide-awake engineers and firemen to exhibit their efficiency and to show that unsatisfactory performance is due to causes beyond their control. Even if no report is expected of him the engineer should keep some form of log, no matter how simple, in order that he may have before him information which will permit him to investigate the resources of the equipment in his charge so that he can secure from it maximum output at minimum cost, and so that failure on the part of the management to supply him with proper facilities for doing the work expected of him will be placed on record for his protection.

The amount of detail which is contained in the report to the management and the frequency with which reports are to be submitted depend on the use to which they are put. If the total cost of fuel and wages and the number of kilowatt-hours of power generated and the cost per kilowatt-hour only is wanted, the report should include only these; if data as to the kind of coal, the amount of ash, amount of water and the quantities of the various supplies used, separation of labor costs into boiler and engine room help are required, the report must show these items in detail. In larger plants the management will desire a record of the number of hours of service rendered by each unit, will want the labor cost to be divided into attendance and repairs, will expect hourly temperature, barometric and steam pressure readings, temperature of feed water and hourly-watt-meter readings. Comparison of the various records will permit keeping a close check on the plant efficiency and show the probable location for most advantageous expenditures for equipment. Many plants have found it has paid them well to record the air pressure below the grate, draft in the furnace, and in the breeching, to take hourly readings of the CO_2 in the flue gas, to watch the smoke, to record tests of boilers, pumps and engines,

Costs in Dollars

192 -	Coal	Oil	Packing	Waste	Genl. Supplies	Labor	Repairs	Renewals	Kw. Hrs. Produced	Boiler Hp. Produced	Ave. Outside Temperature	Hrs. Exhaust Steam On	Hrs. Live Steam On	Total Costs
Jan														
Feb.														
Mar.														
Apr.														
May														
June														
July														
Aug.														
Sept.														
Oct.														
Nov.														
Dec.														
Total														

FIG. 1. YEARLY POWER PLANT SUMMARY OF COSTS

to keep track of all repairs done by power plant employes on outside work, to record the length of time required for the coal-handling machine to accomplish its work, etc. All these data individualize the log sheets of the various power plants and make the planning of each sheet a separate problem.

Just how frequently reports are turned in depends in large measure on the needs of the accounting department and, as previously suggested, on the attitude of the management with respect to the plant. If the general superintendent asks for only a monthly report showing the daily performance of the plant, hourly data will not appeal to him; he should be given a daily summary of only those items which interest him. Nevertheless it will be necessary for the engineer to make frequent readings in order that he may give a fairly correct

POWER STATION REPORT Month of 191

Gas,	Cu. ft.
Water,	Gals.
Loop and Feeders,	K. W.
Sabraton Railway,	K. W.
Total D. C.,	
Incandescent Light Circuit,	K. W.
Arc Light Circuit,	K. W.
Commercial Light Circuit,	K. W.
High Tension Circuit,	K. W.
Commercial Motor Circuit,	K. W.
Total A. C.,	" "
Grand Total,	" "
A. C. Charge,	%
D. C. Charge,	%
Gas per K. W. Hour,	Cu. ft.
Water per K. W. Hour,	Gals.
Water per Cu. ft. Gas,	Lbs.
Crank Case Oil used,	Gals.
Cylinder " "	"
Engine " "	"
Turbine " "	"
" "	"
Boiler Compound "	"
Waste "	"

Engineer

FIG. 2. MONTHLY REPORT BLANK USED BY A STREET RAILWAY COMPANY

average for the day, for his own use and for future requirements. These readings may as well be kept on file. The larger plants require daily reports.

Obviously if the plant manager does not know the relationship between the feed water temperature and the amount of coal burned or any other technicality of operation, he will not care for such data as feed water temperature. When the engineer wants to put in a requisition for equipment, however, he will, if he is progressive, have convincing information at hand in the shape of operating data to prove the need.

So in each case the engineer will submit, preferably, only such data as is wanted of him and in as simple and concise a manner as possible. He will, however, at all times maintain records containing sufficient detail so that he can, at the proper time, show the management either that the plant is being operated in the most economical manner or where improvements can be made which will result in appreciable savings.

Starting with simple yearly, monthly, weekly and daily reports and progressing to those more detailed and complete, we shall in the succeeding pages present a logical method of procedure in planning a system of reports designed to meet the needs of the individual plant.

Power plants of the individual or isolated type usually have as their competitor the central station. The management, therefore, wants to have some means of comparing the cost of the service which he receives from his plant with what it would cost from a central station. Since power is purchased on the kilowatt-hour basis, we must reduce our costs to that per kilowatt-hour. The division of the costs between heat and power where exhaust steam is used for heating purposes is always a

_____ DIVISION

WEATHER - NOON 19

				hr.	min.
Engine No. 1	started ____ M	stopped ____ M	Total time run		
Engine No. 2	" ____ M	" ____ M	Total time run		
Inc. Current on	____ M	off ____ M	Total time on		
Street Arcs on	____ M	off ____ M	Total time on		

AMPERE READINGS

noon																			
12 00	12 30	1 00	1 30	2 00	2 30	3 00	3 30	4 00	4 15	4 30	4 45	5 00	5 15	5 30	5 45	6 00	6 15	6 30	
6 45	7 00	7 15	7 30	7 45	8 00	8 15	8 30	8 45	9 00	9 15	9 30	9 45	10 00	10 30	11 00	11 30	12 00	1 00	
2 00	3 00	4 00	5 00	5 15	5 30	5 45	6 00	6 15	6 30	6 45	7 00	7 15	7 30	7 45	8 00	9 00	10 00	11 00	

Coal used	lbs.	Coal Received on track	Boilers in Service
Cylinder Oil	pts.	Car No.	No. 1 from m to m
Engine Oil	pts.	Initial	No. 2 from m to m
Waste	lbs.	Time Placed m	No. 3 from m to m
Water	cu. ft.	Time Released m	Washed No.
Carbons		Weight lbs.	Blew No.
Globes outer	inner	Ashes Sold loads to	

Material Received for Power House use

Total Kilowatt Output
Read meter 12 o'clock noon

Meter today K.W.
Meter yestdy. "
Diff.

Report here ANY interruption of service either arc or incandescent.

Time off Cause
Arc Lights out
" Location Reported by

FIG. 3. SHORT FORM FOR DAILY REPORT SUITABLE FOR OFFICE BUILDING PLANT

matter of controversy, so the owner will want to know the average outside temperature, the number of hours that exhaust steam heat only is used and the number of hours live steam is used during the month.

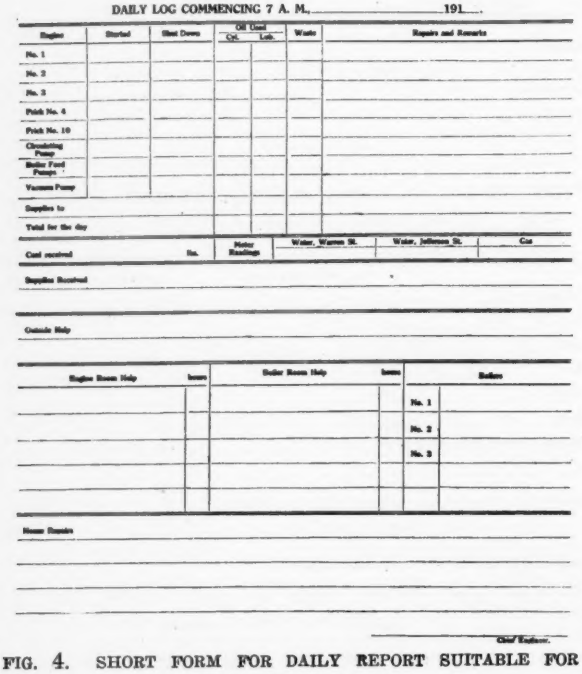
Every good business man will also want to know the boiler horsepower-hours developed for comparison month by month with the kilowatt-hours of power produced. Then he will wish to know the cost of the principal supplies and of labor. Thus we have planned a sheet, Fig. 1, which provides space for a whole year, the totals or averages for each month being given separately.

Starting from this point, which we have assumed in this case is all the information which the superintendent or owner requires, it will be necessary to work back to the source from which we can get the required information. Each plant has its own method of purchasing fuel and supplies and the chief engineer is responsible for

these items from the time they are delivered to any employe working under his direction; he should have, then, some written evidence as to when, to whom, how much and for what purpose supplies are delivered.

Each item takes a different course through the plant, hence the data upon it must be gathered differently, or at least have separate consideration in planning the record system.

The item of coal will be considered first since it is the most important. As we are assuming a small plant, in this instance, we shall also assume that the coal is delivered in trucks day by day, comparatively little being kept in storage. The truck driver will deliver his weigh bill to the fireman in charge, who immediately files it on the engineer's desk. At the end of the day or the first thing the next morning the weights from these receipts are added and the total entered on the daily report sheet; and at the end of the month the


DAILY LOG COMMENCING 7 A. M. 191

Engine	Started	Shut Down	Oil Used Cyl.	Oil Used Lub.	Waste	Repairs and Remarks
No. 1						
No. 2						
No. 3						
Frick No. 4						
Frick No. 10						
Circulating Pump						
Boiler Feed Pumps						
Vacuum Pump						
Supplies to						
Total for the day						

Coal received	lbs.	Meter Readings	Water, Warren St.	Water, Jefferson St.	Gas

Supplies Received

Outside Help

Engine Room Help	hours	Boiler Room Help	hours	Boilers
				No. 1
				No. 2
				No. 3

Home Remarks

Chief Engineer.

FIG. 4. SHORT FORM FOR DAILY REPORT SUITABLE FOR SMALL CENTRAL STATION

total weight is found and the cost recorded in the monthly report.

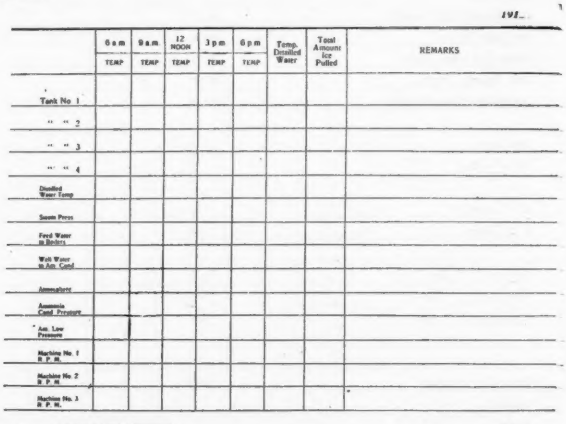
In a similar manner oil, packing, waste and general supplies may be taken care of, as in a plant of this size they usually come to the plant direct so that the engineer will receive the bill when the article is delivered. It is not advisable for the engineer to allow these bills to accumulate on his desk as the likelihood of some becoming lost is too great and the clerical work, if allowed to pile up, will prove irksome. A daily report sheet on at least one line in a weekly or a monthly report sheet will be necessary where cost data only are required by the management.

Power plant labor is usually paid by the month, but frequently extra help is hired by the day or hour. In that case their time should be kept each day and their wages entered in the proper column for the day or days on which the help was employed. The total at the end of the month would of course include the salaries of all power plant employes.

In the small plant it is not customary to carry a large stock of repair parts on hand, so it would be entirely practicable to charge these in the record on the day of receipt; repair work done outside the plant would be entered on the day the work was done or delivered.

What may be classed as renewals are replacements of entire units. This work in small plants is usually done by contract and the cost can therefore be entered at the end of the month after the work is completed.

This completes the items of cost usually required by the management of a small power plant. As stated above, however, he needs to make comparison with services from an outside source, so he will no doubt require the total number of kilowatt-hours of power generated, which can be read from the plant wattmeter each day. Likewise the boiler horsepower produced or feed water evaporated is taken from the feed water meter, which should be demanded if the management requires this item.


191

	6 a.m. TEMP	9 a.m. TEMP	12 NOON TEMP	3 p.m. TEMP	6 p.m. TEMP	Temp. Distilled Water	Total Amount Ice Pulled	REMARKS
Tank No. 1								
" " 2								
" " 3								
" " 4								
Distilled Water Temp								
Steam Press								
Feed Water in Boilers								
Well Water in Am. Cond								
Ammoniator								
Ammonia Cond Pressure								
" Am. Low Pressure								
Machine No. 1 R. P. M.								
Machine No. 2 R. P. M.								
Machine No. 3 R. P. M.								

Amount Coal Consumed ..... *Engineer.*

FIG. 5. ENGINEER'S DAILY REPORT SHEET FOR AN ICE PLANT

In all of the above items only one entry a day has been suggested, in fact in a small plant running on one shift a day more frequent entries would be useless for the items enumerated. If, however, the manager wished to know outside temperature, hours in which exhaust steam only is used for heating and hours combined exhaust and live steam are used, it would be advisable to have a separate daily log sheet on which is recorded, each hour, the temperature conditions and heating arrangement. This would entail but little work on the part of an assistant engineer and the results of the day would be entered in the monthly record for that day.

The same principles can be used in planning a system of cost records for any type of plant, whether it is a small central station, railway plant, office building, factory, or ice and refrigerator plant, the idea being kept in mind that all costs must be entered and all services measured.

Cost Records for Medium-Sized Plant

As the size of a power plant increases and its service broadens the simple cost record sheet explained above is no longer adequate. The management will take greater care to secure economy and will want more de-

tailed information in regard to costs and the program of operation of the machinery, although it is not likely that the management of such a plant, that is, one which is a department of some industry, will be sufficiently familiar with the technicalities of operation to use, intelligently, operating data which are under the control of the power plant force, such as drafts, temperatures, pressures, gas analysis, etc.

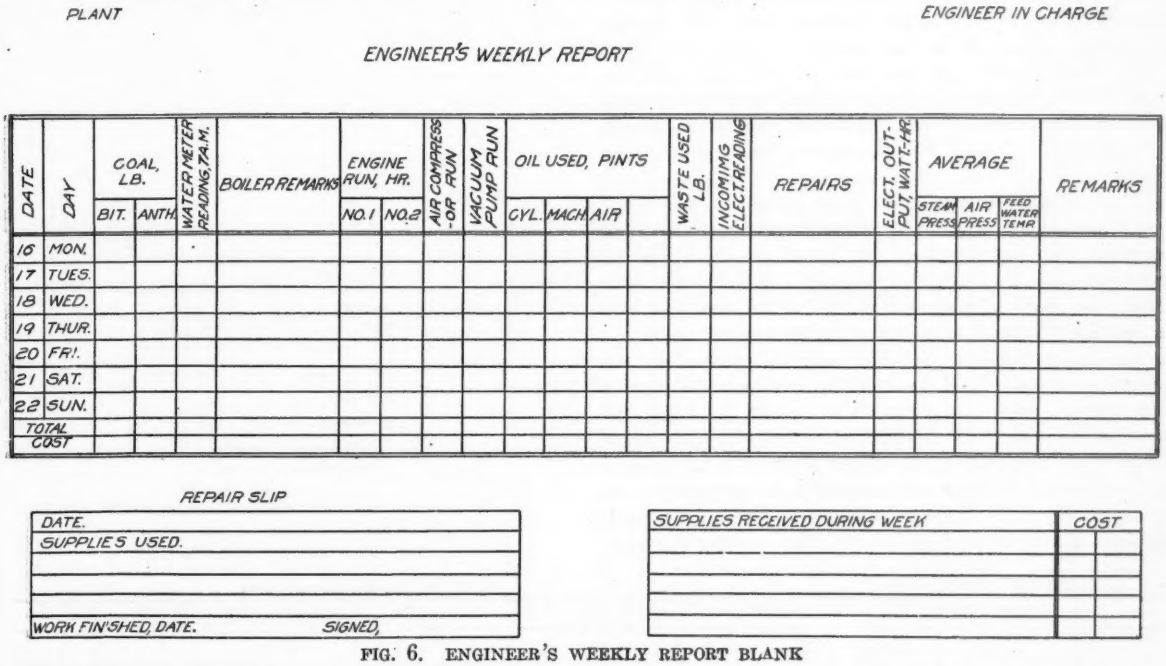


FIG. 6. ENGINEER'S WEEKLY REPORT BLANK

It is for such a plant that the monthly report shown in Fig. 7 was designed. In this case, considerable coal is kept in storage, so to get an accurate record of coal burned it must be weighed as it is delivered to the boiler room or to the individual boilers. It is necessary therefore to provide the man in charge of the boiler room with a blank on which he can record the weights of the cart loads as they come into the boiler room, or an integrating coal meter, from which the day's consumption can be read. The weight of the ashes is also required and the means for recording this depends upon the method of delivery. If removed from the plant daily by means of trucks, their weight should be recorded; but if removed by wheelbarrows to a pile, the average weight of a wheelbarrow load should be ascertained and the number of loads recorded. In either case several entries must be made during a day, so that it would seem advisable for the head fireman to be provided with an individual daily report blank, on which would be recorded coal received at the plant, pounds burned, tons in storage and ash removed, and, in addition, space may be provided for any operating data which the engineer wishes to have regarding the boiler room; this will be taken up in another article, as we are dealing now only with cost data.

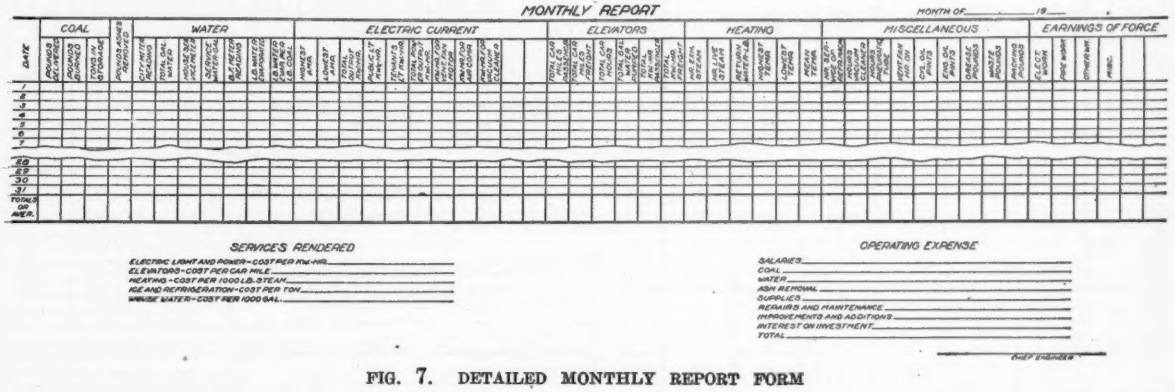


FIG. 7. DETAILED MONTHLY REPORT FORM

Items regarding water used, electric current and elevators in this monthly report to the management are taken daily from meter readings and need no further comment here. The heating system, however, will need some special attention and also the miscellaneous items. These daily records can most conveniently be kept by one of the operating engineers, so that a special form should be provided for his use.

In a plant of this size, oils, waste and packings will most likely be purchased in quantities, so that the plant should be charged for these items as required for use.

This method gives a better means of checking the economy in its use than is possible by charging the plant a lump sum once or twice a month.

The meaning of other items in this monthly report sheet will be clear from what has already been said, and the method of gathering the data will present no difficulties. In this system there would be a daily report from the boiler room, and another from the engine room, once a day the meters would be read, work slips would be handed in at the close of each day and the completion of a job; a separate daily record of repairs and maintenance, improvements and additions would be kept and entered as a summary on the monthly report.

If at all practicable, this report should be made out by the engineer at the head of the plant, if not, a clerical assistant may be employed, but by all means the chief engineer should study this report carefully for any possible revision of program which would result in better service at equal or reduced cost.

An understanding of the principles involved in the foregoing systems will enable the engineer to plan a cost record system for any plant except, perhaps, the very largest industrial plants or central stations, where the expenditures for various items amount to large sums and redivision between departments is necessary. In such plants, each department turns in its daily report, the data is summarized and distributed among the various accounts in such a way as to give the superintendent a comprehensive idea regarding the financial status of his plant. It is, therefore, essential that we go into this question more in detail, show the inter-relation of expenditures and present forms which have been used successfully for keeping records of the different accounts. The following paragraphs are devoted to a discussion of the data necessary for securing unit costs and special forms for reporting different items entering into unit cost calculations.

DAILY

COAL TICKET.

No.______ ________191__

6 A. M. to 6 P. M.		6 P. M. to 6 A. M.	
LBS. COAL.	LBS. ASHES.	LBS COAL.	LBS. ASHES
KIND OF COAL.		KIND OF COAL.	
Fireman.		Fireman.	

Coal Used______lbs.
Ashes Made______ "
% Ashes______ "
Water Used______Gals.
" " ______lbs.
" ______lbs. to 1 lb. Coal.
Boiler Water Test: Good. Med. Low.

FIG. 10. DAILY COAL TICKET

Power Plant Operation Record

		SUNDAY		MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY		SATURDAY	
	HR.	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
Volts	7														
Steam	7														
Receiver	7														
Outdoor Temp.	7														
Vacuum	7^{5}														
	9														
	11^{55}														
	1^{5}														
	3^{30}														
	5^{55}														
Eng. 1—Amps.	7^{5}														
	9														
	11^{55}														
	1^{5}														
	3^{30}														
	5^{55}														
Eng. 2—Amps.	7^{5}														
	9														
	11^{55}														
	1^{5}														
	3^{30}														
	5^{55}														
Eng. 3—Amps.	7^{5}														
	9														
	11^{55}														
	1^{5}														
	3^{30}														
	5^{55}														
KVA															
KW @ % P.F.															
Hours															
KW Hours															
KVA															
KW @ % P.F.															
Hours															
KW Hours															
KVA															
KW @ % P.F.															
Hours															
KW Hours															

Power Plant Cost Sheet for week ending ______191

EMPLOYEES	SUNDAY		MONDAY		TUESDAY		WED'DAY		THURSDAY		FRIDAY		SATURDAY		TOTAL	RATE	AMOUNT
	DAY	NT	DAY	NT.	DAY	NT.	DAY	NT.	DAY	NT.	DAY	NT.	DAY	NT.			
Cylinder Oil, Gallons																	
Engine Oil, Gallons																	
Coal, lbs., on hand -Rec'd																	
Water, cu. ft.																	

Boiler Room Supplies, Forward $ —This Week $ —To Date $ Per Week
Boiler Room Repairs, Forward $ —This Week $ —To Date $ Per Week
Fixed Charges, Per Schedule
Cost Per Boiler H. P., Est. On Feed Water Boiler Total
Engine Room Supplies, Forward $ —This Week $ —To Date $ Per Week
Engine Room Repairs, Forward $ —This Week $ —To Date $ Per Week
Fixed Charges, Per Schedule
Cost Per I. H. P. Hr. Per K. W. Hr. Engine Total

FIG. 8. WEEKLY REPORT SHEET OF OPERATION AND COST

Unit Costs

The unit cost of production of power, steam, water and the other output of a power plant is computed from data which will fix: (A) the total cost of production, (B) the amount of the corresponding output. Each of these general divisions is further subdivided into its component parts and the whole can be outlined as follows:

Necessary Data for Unit Costs

- (A) Cost of Production
  - Variable Charges
    - (1) Cost of Fuel
    - (2) " " Water
    - (3) " " Oil, Waste and Supplies
    - (4) " " Labor
    - (5) " " Repairs — Maintenance — Upkeep Costs
    - (6) " " Renewals — Maintenance — Upkeep Costs
  - Fixed Charges
    - (7) " " Obsolescence and Inadequacy — Annual Depreciation — Upkeep Costs
    - (8) " " Insurance
    - (9) " " Taxes or Rent
    - (10) " " Interest on Investment
    - (11) " " Management (overhead)
- (B) Output
  - (12) Amount of Steam Delivered
  - (13) " " Power "
  - (14) " " Water "
  - (15) " " Ice "

Cost of Production is divided into the two general subdivisions of variable charges and of fixed charges. Costs listed as variable are those which increase or decrease with the size of the output. Fixed charges remain practically constant whether the output be great or small.

As will be explained later, upkeep costs contain both variable and fixed items and their relation to each other is indicated in the chart.

In planning a log sheet and records which will give the information needed for determining the costs as outlined in the chart it is necessary to know whether the unit costs are to be computed daily, weekly, or monthly. The larger public service plants will ordinarily expect figures daily, the smaller ones and industrial plants weekly or monthly.

It should be understood that whereas items 1 to 6 require the making of entries daily and in some cases more frequently, items 7 to 11 remain practically without variation the year 'round, and need attention rarely.

We shall discuss methods for keeping the costs of the various items of expense in the order that they have been presented and in each case present a form which will fill the requirements.

With respect to these forms, it is not desirable to place on the average power plant engineer the burden of doing the work entailed by an exhaustive and complicated system of accounting. Unessentials which would secure refinements not desirable from the point of time involved have been eliminated. The superintendent of a small power plant may wish to reduce still further the amount of detail which is suggested here and omit some items. This may be highly desirable for the time being. But, as the plant is enlarged he will have before him this general outline which will possess the undoubted advantage of providing the backbone for an extended system of log sheets which will enable him to provide for data heretofore omitted and which will, moreover, tie in with that previously obtained.

(1) Cost of Fuel

Fuel is the largest single item of cost in power production and a complete and careful record of fuel consumption is vital to the progressive engineer. The coal record shown in Fig. 11 is a simple form designed to give all the data required to determine coal costs. As each car comes in the data necessary are entered in the proper columns. The second column will give the car initials besides the car number, in order to provide a means of checking with the bill of lading sent by the dealer or mine operator.

THE SUBURBAN R . R . CO.

DATE — BOILER HOUSE LOG — WATCH 8 A.M. TO 4 P.M.

BOILERS					COAL	ASH	FEED WATER METER	TEMPERATURES
1	2	3	4	5				OUTSIDE
								BOILER ROOM
								COLD WATER
					FEED PUMPS		MAKE UP METER	HEATER OUTLET
					1	2	3 4	ECON. OUTLET
								STACK
					REMARKS			FIREMAN
								COAL PASSER

THE SUBURBAN R . R . CO.

DATE — ENGINE ROOM LOG — WATCH 8 A.M. TO 4 P.M.

HR.	ENGINES			PRESSURES				COND.			PUMPS			REMARKS
	1	2	3	REC.		VACUUM		1	2	3	1	2	3	
				1	2	1	2	3						
														ENGINEER
														OILER
														HELPER

THE SUBURBAN R . R . CO.

DATE — ELECTRICAL LOG — WATCH 8 A.M. TO 4 P.M.

HR.	AMPERES		VOLTS	POWER		LIGHT		STATION		REMARKS
	GEN. 1	GEN. 2		LINE 1	LINE 2	LINE 1	LINE 2	PWR.	LGT.	
										ELECTR.
										HELPER.

FIG. 9. DAILY FORMS OF DIFFERENT DEPARTMENTS FOR EACH SHIFT

Under the head "kind" should be specified bituminous, anthracite, lignite, etc. The size, fourth column, should indicate whether run of mine, egg, nut, pea, or slack is used.

Under "mine" it is desirable that the name of the mine producing the coal be given. This item is valuable as it frequently permits the exact specification or rejection of coal without further investigation. Furthermore, it enables the making of comparison between analyses made for the purchaser in his own laboratory or elsewhere, with those made by the U. S. Bureau of Mines. These are published at Washington as bulletins for free distribution.

Undesirable ingredients of the coal can frequently be detected and guarded against by examination of the reports showing chemical analyses of the coal, and descriptions of the various strata such as shale, bony coal, limestone, etc., between which it lies. If the coal is purchased direct from the producer at the mine, the name of the mine is readily obtainable; if from the jobber, it will usually be given if requested.

The next column headed "Dealer's Name" is readily filled out as is the one following which calls for the weight of coal as given by the dealer's scales. To check up on this weight the purchaser should in every case reweigh the coal and record that weight as in the next column. Discrepancies will indicate loss in transit through leakage, pilfering, etc., which may be grounds for complaint to the railroad management, or they may show serious shortage in loading at the mine, defective scales, etc., and should call for immediate notification to the mine or dealer.

It must be remembered, however, that coal containing 5 per cent or more of moisture tends to lose moisture and necessarily weight, while in transit. Low-moisture coals shipped in open cars may gain or lose moisture depending on weather conditions during transit.

Values for the next three columns, B.t.u. (British thermal units) per lb., per cent ash, and per cent moisture, are obtained either by testing in the purchaser's laboratory, by submitting samples for testing to recognized commercial laboratories, or by consulting the Bureau of Mines bulletins just mentioned. Looking up the chemical composition of the coal in these bulletins is a simple matter, provided the name of the producing mine is known. This is another reason for urging the engineer to obtain the name of the mine or mines which produce his coal.

A chart for determining the heat value of a coal sample, if a proximate fuel analysis is known, is shown in Fig. 12.

In order to use this chart it is necessary to know three percentages: (1) fixed carbon, (2) ash, and (3) moisture. Proceed then as follows: Run a straight line from the fixed carbon (column A) to the sum of moisture and ash (column B) and locate the key in column D. Locate this key number in column E, called Transfer, and connect it with the sum of moisture and ash (which has already been located in column B) and the intersection with column C gives the heat value of the coal.

The importance of determining the percentage of ash is shown at a glance at Fig. 13 plotted from results of tests conducted by the U. S. Geological Survey. The curves of efficiency, horsepower, and value follow along about in the same relative positions and taking their values as 100 with coal having no ash content, all come down to 0 when the ash equals 40 per cent of the total dry weight of the coal. In other words, coal with this excessive amount of ash has no heat value and is worthless.

Moisture in coal greatly affects its heat-giving properties and it can be shown that moist coal with a heating value of 11,000 B.t.u. per pound corresponds to coal having 8.3 per cent moisture and giving 12,000 B.t.u. per dry pound; and moist coal with a heating value of 9000 B.t.u. per pound corresponds to coal having 10 per cent moisture and giving 10,000 B.t.u. per dry pound.

The next to the last item "Cost per ton" is recorded without difficulty. Under the last head "Cost" is entered the product of the weight by the cost per ton.

Data recorded on the coal sheet as the coal is delivered are summarized at the bottom of the sheet either daily or at least once a month to give average values to be used for cost analyses.

COAL RECORD

NAME _____ MONTH _____ 19__

DATE	TICKET OR CAR NO.	KIND	SIZE	MINE	DEALER'S NAME	DEALER'S WEIGHT	CITY SCALE WEIGHT	DIFFERENCE IN WEIGHT		B.T.U. PER LB.	PERCENT ASH	PERCENT MOISTURE	PRICE PER TON	COST
					BALANCE ON HAND FIRST OF MONTH		( )							

FORM APPROVED BY JOSEPH HARRINGTON ADMINISTRATIVE ENGINEER FOR ILLINOIS

TOTAL _____
COAL USED _____
BALANCE ON HAND _____

_____ CHIEF ENGINEER.

FIG. 11. FORM FOR SCIENTIFIC COAL RECORD

(2) Cost of Water

Where water is secured from city service mains, a water meter reading once a week or once a month to check with reading by water department as shown in Fig. 14 will suffice. In large plants daily readings are necessary.

If water is secured from a lake, river, or similar source by means of specially constructed intakes, service mains and pumps, the cost of these and such other items as apply among the first eleven given in the chart should be computed so that the annual charge due to maintaining the water plant can be determined. This can be prorated per gallon of water recorded on the water meter. The cost of standpipes or storage tanks and reservoirs is similarly charged to the cost of water.

Frequently it is desirable to add the cost of the stand-

pipe and other equipment, which is part of the water supply system, to the total investment for the plant and then the interest, depreciation and other factors are considered a part of the general fixed charges, the same as similar items pertaining to the power plant building. In this case, however, no cost comparison is possible between the cost of production in such a plant and one in which the water is furnished without the necessity of building water storage facilities.

For convenience provision should be made on the water meter blank for readings of all water meters in the plant which will save considerable confusion when making up the daily plant report.

(3) Cost of Oil, Waste and Supplies

A perpetual inventory as shown in Fig. 15 will always give immediately the amount of supplies on hand

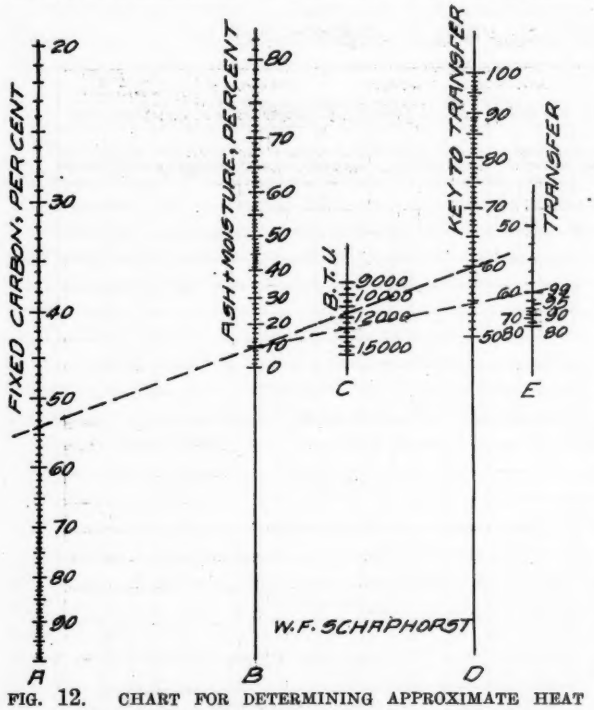


FIG. 12. CHART FOR DETERMINING APPROXIMATE HEAT VALUE OF COAL

and their value, provided the price remains constant. Materials which are graded, and consequently of various prices, should preferably be given separate columns. For instance, if cylinder oil is purchased as grades 1 and 2 they should be listed separately in order that the value at the bottom of the table may be a measure, also, of the quantity. This record may be kept weekly or monthly and the totals computed accordingly. In a large power house the storekeeper will keep the record; in a smaller one an engineer can make the entries at the time they are taken from the store room. It should be noted that the amount used by each shift is also recorded; in plants with one shift this item is omitted. The columns marked "Value" are also sometimes omitted and provision made only for entering receipts and disbursements.

(4) Cost of Labor

The daily log sheet should contain items shown in Fig. 16 which pertain to labor costs, this data being obtained from work slips handed in by employes.

Direct labor charges are readily computed from a record of attendance for which a place is provided on the general form sheet. The total hours worked multiplied by wages per hour for each individual should be computed daily in large plants, weekly in small ones. Only such labor as is actually used in the operation of the power plant should be charged against this item, as general superintendence which continues whether or not the plant is productive must be classed as a fixed charge

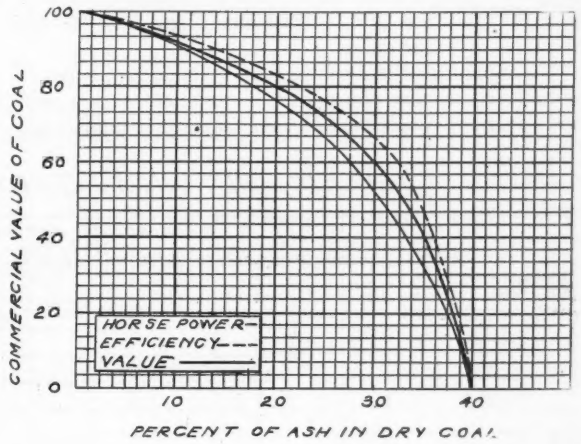


FIG. 13. RELATION OF ASH PERCENTAGE TO BOILER EFFICIENCY

and is so listed in article 11 under "Management." Under direct labor are listed the service of the assistant engineers, oilers, firemen, coal passers, ash removers, storehouse men, and miscellaneous labor.

Labor chargeable to maintenance must not be included in attendance costs and should be definitely separated and charged to repairs or renewals as the case may be. A place for such items is shown in the second section of the table, which comprises labor costs for repairs and renewals. These should include only such as may be considered as work over and above ordinary attendance. These items can be transferred daily or monthly to the repairs or renewals accounts.

Watermeters

Meter	Present reading			Last reading			Elapsed time hr.	Quantity used gal.
	Date	Hour	Reading	Date	Hour	Reading		
City Supply								
Boiler Feed								
Plant Service								

FIG. 14. FORM FOR RECORDING WATER METER READINGS

Furthermore, the cost of electrical and repair work done by employes of isolated stations for the manufacturing or producing divisions of the plant should likewise be subtracted from the charges set against operating. It is sometimes advisable, in order to show the real cost of producing power in such a plant, to class such work done for other units of the plant as income producing. This is done by deducting from total operating expenses the value of such work, assuming that it was done by an outside contractor at the prevailing wages of each craft.

Deductions for labor not chargeable to power produc-

ing can be totaled monthly and together with items mentioned in the preceding paragraph subtracted from total labor cost for the month to give net labor attendance costs.

(5), (6) and (7) Upkeep Costs

The annual upkeep expense consists of annual repairs plus annual depreciation, which in turn is both natural and functional. Natural depreciation is due to physical decay, the action of nature, and is provided for by annual renewals which consist of expenditures for renewals of plant units. The functional depreciation of plant equipment is due to inadequacy and obsolescence which we will now define.

Many manufacturing businesses of today are expanding rapidly so that equipment in excellent repair and good for many years of additional service is inadequate to supply the demands made on it and must be replaced by larger units or equipment of a different type. For instance, more boilers have to be built and higher pressures used; the piping would then be inadequate. Inadequacy is not related to physical decay or wear and tear; it cannot be forecast and must usually be provided for by allowing a certain percentage of the value of the equipment annually.

Modern science related to the generation and efficient use of power has developed remarkably in the last few years. Reciprocating engines have in many cases given way to steam turbines, individual motor drives have replaced belt drives, superheated steam has replaced saturated steam; and competition for business has forced many a plant owner to scrap perfectly good machinery destined for many more years excellent service, and buy improved apparatus that would save in operating costs. This decline in modernity is called obsolescence and is estimated variously, although it cannot be forecast.

Thus the various factors which go to make up functional depreciation cannot be measured nor foreseen, as it takes place whether the equipment is used or not. It is therefore not due to nature but to social progress and must be provided for in the same manner as fire insurance, by the setting aside of a fund to take care of future obsolescence or inadequacy. Functional depreciation depends on functional life which is the estimated number of years that a plant unit will remain in use before it is superseded by an improved or more adequate unit. A functional depreciation factor of 2.5 to 3.5 per cent per annum is justified by experience.

Annual repairs are *not* a part of annual renewals and it is very important that the two terms be not confused. Repairs expense consists of expenditures for keeping *parts* of plant units in serviceable condition while renewal expense consists of the replacement of entire units. Just what should be called a plant unit? This question has been answered in a variety of ways and we show in Fig. 18 the generally accepted distinction between renewals and repairs which answers the question in a satisfactory manner. Further, the size of the expenditure is often used as a criterion to distinguish between repairs and renewals by specifying that a repair is maintenance costing, say, not more than $50 per item and in general the renewal of all short-lived, small-priced elements. Such, for instance, are boiler tubes, fire-brick, gage glasses, valves, etc. A replacement of a long-lived, high-priced element such as a boiler, engine, turbine or generator is termed a renewal, and, as the diagram shows, is chargeable to annual depreciation.

Ledger accounts should distinguish between annual

DAILY OIL, WASTE AND SUPPLY RECORD

	CYLINDER OIL			ENGINE OIL			KEROSENE			GREASE			WASTE			RAGS			PACKING			BOILER COMPOUND		
	GAL.	@	VAL.	GAL.	@	VAL.	GAL.	@	VAL.	LB.	@	VAL.	LB.	@	VAL.	LB.	@	VAL.	LB.	@	VAL.	BBL.	@	VAL.
CARRIED FORWARD																								
DATE SHIFT	RECEIPTS			DRAWN	RECEIPTS		DRAWN	RECEIPTS		DRAWN	RECEIPTS		DRAWN	RECEIPTS		DRAWN	RECEIPTS		DRAWN	RECEIPTS		DRAWN	RECEIPTS		DRAWN
1																								
2																								
3																								
30																								
31																								
TOTAL RECEIPTS																								
TOTAL DRAWN																								
ON HAND																								
	CYLINDER OIL			ENGINE OIL			KEROSENE			GREASE			WASTE			RAGS			PACKING			BOILER COMPOUND		

FIG. 15. DAILY OIL, WASTE AND SUPPLY RECORD

repairs and annual renewals. Sometimes these are combined to give the annual maintenance cost, but it is strongly urged that in the original entry these be separated.

Costs of repairs and renewals should further be subdivided into labor and material costs. Ordinarily, the help around the power plant does all the repairing and other maintenance work and the cost of such labor should be recorded as shown in the table given in the preceding section and deducted from the operating labor cost. Cost of outside labor employed for the purpose should of course be recorded. The cost of the material used for repairs, if it is drawn from shop supplies on hand, must be deducted from supply costs charged to attendance. Repair parts purchased to renew those broken or worn out will, of course, be charged directly to maintenance account.

Renewals and repairs should also be entered in the plant ledger against the respective equipment on which the work is done.

(B) Fixed Charges

The production cost factors listed as fixed charges are as a rule not among the items on the daily log sheets. The relative value of each of these as a percentage of the total cost of production is determined once or twice a year and added, on the monthly log sheet, to the summarized operating costs to give the total monthly cost of production.

The fixed charge which we have designated as functional depreciation has already been discussed. A brief explanation will now be given of the other factors making up the total fixed charges to show the method used in arriving at their value.

(8) Cost of Insurance

Insurance on a power plant is divided into insurance on buildings, insurance on equipment and liability insurance on employes. It is paid for in the form of a premium which bears a definite relation in the first two cases to the value of the plant assigned to it by the owner, and in the last case, to the hazard of the labor and its cost. If old machinery is replaced by new and more expensive machinery, it is advisable to have the policies revised to take this new value into consideration in order to make the protection adequate; insurance companies assuming risks in the case of workmen's liability insurance insist that a careful record be kept of the employes' time to distinguish the various occupations which bear premiums dependent on the risk of life involved.

Property insurance costs remain the same, especially if paid on the basis of a term of years, excepting when additions or alterations to the plant itself are made, or if structures which change the fire hazard are erected or removed on adjoining property. If the hazard is lessened, it will be to the owner's advantage to have his policies canceled if the clauses providing for such cancellation are still in effect, and to have new policies written. Increase in fire hazard is generally followed by cancellation or rewriting and increase in premium at the discretion of the insurance companies.

It is well to note that with present high prices for building and equipment, insurance based on old costs is entirely inadequate and will involve serious impairment of funds available for replacements, in case of fire loss.

For the purpose of the cost record the amount of the yearly plant and equipment insurance should be divided by the total operating costs for that year and the percentage used as the factor to be averaged with similar factors derived for other years. The general average so obtained can be used in connection with the other fixed charges, and added as a percentage or a sum to the monthly or yearly operating costs to arrive at the total cost of production for the period of time desired.

With laws respecting the liability of the employer, as regards loss of life or limb of employes incurred in or by reason of his employment at a certain occupation, almost of universal application, workmen's liability insurance has come to assume a very important place in power plant costs. The insurance premium is generally fixed

Description	Rate per hr.	Total hr.	Amount $	Remarks
Asst. Engrs.				
Oilers				
Firemen				
Coal Passers				
Watchmen				
Other help				
Total Gross Labor Cost (A) $				

Deductions for Maintenance to Power House Equipment

Description of Work						
Name or No. of Equip.	Kind of Work done. State Whether Repair or Renewal	Name of workman	Rate per hr.	Total hr.	Amount $	
Total Deduction for Power House Maintenance (B)					$	

Deductions for Construction and Repairs not for Power House

Description of work						
Location	Kind	Name of workman	Rate per hr.	Total hr.	Amount $	
Total Deductions for Out of Power House Labor (C)					$	
Grand total deductions for labor for non-operating purposes (B + C)					$	
Net labor attendance costs A-(B + C)					$	

FIG. 16. DAILY REPORT SHEET FOR POWER PLANT LABOR

as a certain percentage of the yearly labor cost which in turn is divided into the various occupations, those more hazardous to life commanding higher premiums. Considering that the premium may be a sum which is 1 to 10 per cent of the actual cost of labor, thus amounting to a very respectable total in a year's time, it is highly desirable that an accurate record be kept of the employes' time to show the class of work done, as it lies to the employer's advantage to have his men work at the machinery or equipment which entails the smaller premium charges.

When no other means for allocating the charges is available, they are based in the case of a power plant auxiliary to an industrial establishment, on the weighted average plant premium paid for all classes of labor—toolmakers, machinists, molders, carpenters, etc.

Whether to consider workmen's liability insurance as

a variable or fixed charge is a matter of opinion—in the first place it can be considered as an inalienable part of the labor cost and thus attached to the labor costs; in the second place it can be considered as a charge similar to that of insurance on plant, or rent, as it is paid only once a year. For the sake of simplicity of recordkeeping we shall consider it as a fixed charge. The form shown in Fig. 16 will ordinarily suffice to provide the informa-

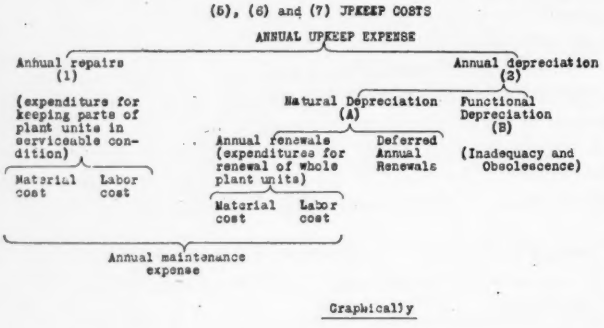


FIG. 17. DIAGRAM SHOWING ITEMS OF ANNUAL UPKEEP EXPENSE

tion needed to compute the amount of the workmen's liability insurance premiums.

(9) Cost of Taxes or Rent

In a great majority of cases land for power plants is purchased outright and taxes are paid both on the land and on a valuation, fixed by local conditions, placed on the plant. In other cases, especially in cities, where land is particularly valuable, rent on the land as called for by a lease is paid to the property owner; the tax on buildings and equipment will be the same as noted above. These figures ordinarily change only yearly and are readily secured and prorated as explained in the discussion on insurance.

(10) Cost of Interest on Investment

Interest on investment is easily computed on the basis of a percentage of the original cost. If a mortgage to cover cost of building has been given, and bonds issued to cover cost of equipment and organization, interest on the mortgage and fees connected therewith and interest on bonds are the items to be classed hereunder as interest. If a plant has been built with money subscribed for that purpose, the income which the money would earn if invested in other business, or if placed out at interest, would be the sum to be set down as interest charges. Interest charges are varied from year to year as the value of the investment and current interest rates increase or decrease.

Reference to the plant ledger, previously described, will indicate increased value of equipment due to betterments, replacements or additions. Expenditures made for repairs and renewals which do not increase the value or efficiency of the equipment beyond its former value must be charged to operating expense.

Additions include expenditures made from structures and equipment previously non-existent.

Betterments include the improvement of facilities previously built.

Replacements include expenditures for machinery or structures substituted for facilities obsolete or inadequate. Only that portion of the cost of the replacement which is above the cost of renewal of the old equipment is charged to capital value. The remainder is charged to operating costs.

From the value of the original investment plus cost of additions, betterments, etc., must be subtracted the depreciation charges described in section 7. The remainder will give the capital value on which to base interest charges. Except in large central plants, adjustments of capital value are usually made but once yearly.

Where the power plant is part of a comprehensive system of buildings, its cost is obtained as part of the whole cost of the project and the interest computed on this part, as it is correct to assume that the power plant should pay for itself. Interest charges for plants of the latter type should be carefully computed as it is entirely possible to fix values which are not equitable so that fair returns on the investment are difficult of attainment. If specific figures are unobtainable, an interest charge of 6 per cent of the original cost of building and equipment may be safely assumed.

The annual cost of interest on the investment can be divided into twelve equal parts and one such part added to the monthly cost of the other fixed charges, or, as explained previously, as a percentage to obtain the monthly cost of production.

Chart showing method used to separate maintenance charges into repairs and renewals.

Plant Units Renewals	Coal Handling Machinery	Boilers	Stokers	Pumps	Heaters	Economizers	Engines	Turbines	Generators	Compressors	Motors
Repairs	Sprocket wheels. Pillow Blocks. Shafting. Buckets. Conveying Belts. Chain. Cars Wheels Chutes Gates	Sheets. Tubes. Pressure gages. Gage glasses. Brickwork, Bridgewalls, Arches, etc.	Links for Chain Grate. Worm Gears: Eccentrics. Sprockets. Grate bars	Piston rings. Cylinders re-bored. Valves	Valves. Gage glass. Trap. Fans Coils. Tubes.	Scrapers. Tubes. Headers. Motor-repairs	Connecting rods. Pulleys. Eccentric. Governor. Valve and gear.	Blades. Disks. Governor.	Brushes. Commutator bars. Field coils.	Valves and Valve gear. Piston rings. Governor.	Armatures re-wound. Brushes. Commutator bars.

FIG. 18. CLASSIFICATION OF RENEWALS AND REPAIRS

(11) Cost of Management (Overhead)

The method of keeping the cost of management and overhead for a central power plant is comparatively

simple. The appended table covers items listed under administrative expenses:

ADMINISTRATIVE EXPENSES

Salaries, officers
Clerical wages
Office supplies
Office rent
Depreciation of office equipment
Repair to office equipment
Insurance on office equipment
Postage
Telephone and telegraph
Legal expenses

For a plant which serves only as a power generating unit in a group of buildings constituting a manufacturing plant some of the above factors are subject to variable modification.

Thus in considering the charge under the heading "Salaries of officers" it should be understood that where a man in charge of the power plant is also engaged in some other capacity in the manufacturing or production division, as for instance, master mechanic, it is essential for equitable distribution of costs that his time be prorated against his various activities. Other items such as office rent and clerical wages will probably occur only in the office of the manufacturing division and will not be charged to power generation excepting where there is a definite relation existing between them. Most of the remaining items in the list given can be omitted.

Management expense is generally figured as a percentage against the total cost of production and would ordinarily vary only slightly from month to month and year to year, except as higher wages and higher prices enter into consideration.

(B) AMOUNT OF OUTPUT

THE OUTPUT of the ordinary power plant is measured by the amount of the steam, power, water or ice delivered. The amount of each of the products, except the third, for any one plant varies considerably, depending for the first and fourth on the season of the year and, for the second, partly on the season and partly on the manufacturing output during the year. The amount of water needed for ordinary plant uses fluctuates slightly from time to time. The method used to record the quantities produced will be described briefly in the succeeding paragraphs.

(12) AMOUNT OF STEAM DELIVERED

IF LIVE steam is used for heating, the amount delivered is recorded on the flow-meter and should be recorded at least every 2 hr.; although during the summer months when the heat is off this reading is not taken, considerable variation, on the other hand, will be experienced in the winter months, depending of course on outside temperatures. If exhaust steam is used, it is sometimes advisable to measure the condensate instead of the steam as more accurate results are possible. The number of hours during which heat is supplied each day is also recorded on the daily log.

(13) AMOUNT OF POWER DELIVERED

THE AMOUNT of power which is delivered by the plant will be measured by integrating wattmeters for the lighting and power services. These instruments are self-recording and, except for test purposes, are read but once daily.

(14 AND 15) AMOUNT OF WATER AND ICE DELIVERED

WATER PUMPED for purposes outside the power plant and the number of cakes or tons of ice pulled each day are other products or by-products of the plant whose quantity is recorded daily. The daily log sheet will suffice for this purpose.

Renewal and Repair Expense Record

Date	Name or No. of Equip.	Kind of Work done	Labor Costs				Material				Charge Total cost to	
			Shop Labor (From Daily Labor Record)		Outside Labor		Quant.	Unit price	Total Material cost		Repairs	Renewals
			$	¢	$	¢						

FIG. 19. FORM FOR REPORTING AND KEEPING RENEWAL AND REPAIR EXPENSE RECORD

To make up a report sheet which will give all the necessary data for calculating unit costs, it is necessary to take each of these factors into consideration, provide means and a system for collecting the necessary data and arrange the items in a convenient form on which they can be entered together with the desirable calculated results such as total cost per kilowatt-hour, water evaporated per pound of coal, cost of 1000 lb. steam, cost of labor per kilowatt-hour, etc. Such a form is not presented here as it is always best to collect operating data at the same time that cost data is being recorded, so complete log sheets will appear in another section of this issue. A condensed monthly summary of cost data, however, is given in Fig. 20 which serves most purposes so far as costs are concerned.

Plant name.....	Month of.....
Coal use.....	Cost of coal.....
Water used.....	Cost of water.....
Water evaporated.....	Cost of oil, water and supplies.....
Total kw. or hp. output.....	Cost of labor.....
Live steam for heating.....	Cost of repairs and renewals.....
Kw. for power.....	Cost of obsolescence and inadequacy.....
Kw. for lights.....	Cost of insurance.....
Water delivered.....	Cost of taxes and rent.....
Ice made.....	Cost of interest on investment.....
Ashes made.....	Cost of management.....
Coal received.....	
Coal on hands.....	
Water evap. per lb. coal....	

Cost coal per 1000 lb. steam.....
Cost per kw.-hr. all charges to switchboard.....
Cost coal per kw.-hr.....
Cost labor per kw.-hr.....

FIG. 20. CONDENSED SUMMARY

THE HIGH COST of living is not the only problem before America, according to Vice-President Thomas R. Marshall. The high cost of leisure is also a menace he says. "One of the old ideas of the republic was that the limit of striving for success was the limit of capacity and endurance," declared the Vice-President recently.

"I only beg the thoughtful consideration of younger men who have the good of the republic at heart, seriously to consider the problem as to whether the only way in which to meet the increasing difficulties of American life is not by additional striving to produce more, to earn more, to economize more and to save more."

Planning Forms for Tests

DATA REQUIRED FOR DETERMINING EFFICIENCIES; CONVENIENT FORMS; FORMULAS FOR CALCULATIONS

ALL POWER plant machinery undergoes constant deterioration or wear, it may also get out of adjustment or alinement or become coated with scale, soot or dirt which prevent it from performing its functions in the most efficient manner. These changes take place gradually in most cases, hence the reduction in efficiency is not noticed until the conditions become quite serious, unless the results of its work are watched constantly and comparisons made with form records.

The engineer's daily record should give an indication of the general results obtained from a piece of apparatus but when these show a falling off which cannot be remedied without more definite information a special test for efficiency should be made which will in many cases determine just where the trouble lies and point

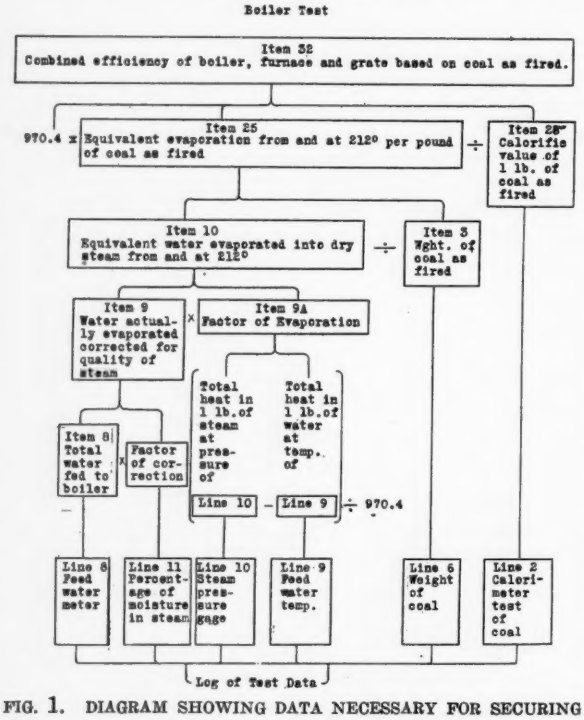


FIG. 1. DIAGRAM SHOWING DATA NECESSARY FOR SECURING VARIOUS ITEMS FROM BOILER TESTS

to changes which can well be made in the program of operation.

In the test forms which follow, it is the intention to include such data as are necessary for determining efficiencies, as this is the most reliable method of comparing the operation of any piece of apparatus with former operation or with other apparatus for the same purpose. Not only is it desirable to compare efficiencies, but the various items entering into the calculations should be compared with more efficient apparatus as such a comparison will frequently show where improvement can be made.

Most of these forms are quite complete but it will be noted that in most cases the data necessarily collected at the time of the test is in few cases more than five or six items from which the calculation of efficiencies can be made. It should also be noted that for some purposes it is not necessary to fill out the entire form given here as will be explained later. Efficiencies of each important piece of equipment should, however, be determined at stated intervals as in this way only can a plant be kept tuned up to its best working condition.

No description is given here of the method of conducing these tests, as it is assumed that the engineer is familiar with the use of the necessary instruments employed, but under the section on analysis, the method of comparing the data gathered will be explained and its relative importance pointed out.

BOILER EFFICIENCY TESTS

BOILER EFFICIENCY tests are of two general types, (1) those in which the boiler and furnace are tested for the amount of heat absorbed as compared with the heat value of the combustible burned, and (2) those in which the boiler, grate (or mechanical stoker) and furnace are tested for the amount of heat absorbed as compared with the heat value of the coal.

Although most boiler tests have been and are of the latter kind, the efficiency of the boiler, not including the grate and furnace, is now recognized as the fairest basis on which to compare different boilers but no agreement has been reached as to the method of separating the boiler and furnace efficiencies. Combined boiler efficiency, as boiler efficiency which includes furnace and grates is sometimes called, introduces a number of variable conditions. Such for instance are the size and character of the coal, errors in sampling the coal, the type of grate or stoker, the skill of the fireman in preventing loss of coal through the grate, etc. It is combined boiler efficiency that is wanted by the average power plant engineer when the efficiency of the steam generating equipment as it stands is to be used for the purpose of comparing with other tests of the same or similar equipment.

Boiler and furnace efficiency is calculated from the formula:

$$\text{Boiler and furnace efficiency} = \frac{\text{Heat absorbed per lb. combustible burned}}{\text{Calorific value of 1 lb. combustible}}$$

in which the heat absorbed per pound of combustible burned is obtained by multiplying the equivalent evaporation from and at 212 deg. F. per pound of combustible by 970.4, and this result is divided by the calorific value of 1 lb. of combustible which is determined by means of a calorimeter. The combustible burned is determined by subtracting from the weight of the coal supplied to the boiler, the moisture in the coal, the weight of the ashes and unburned coals withdrawn from the ashpit and the weight of the soot, dust, etc., which passes off with the gases or collects on the tubes, flues, baffles, etc.

Similarly:

$$\text{Combined Boiler Efficiency} = \frac{\text{Heat absorbed per lb. of coal}}{\text{Calorific value of 1 lb. of coal}}$$

in which the heat absorbed per pound of coal as fired is used as the numerator of the fraction and the heat value of the coal as fired is used as the denominator.

Recording the Data

For the purpose of recording results of boiler tests and to provide convenient and logical forms in which to record the data and computations the two forms shown herewith are recommended. The first form contains only the bare data which are recorded during the test; the second is a summary of the test data and shows the various arithmetical steps which must be taken to get to the point where the efficiency is calculated.

BOILER TEST LOG

Made by_____ on boiler No._____ Date._____

Line No.	Description								
1	Moisture in coal, percent (1)								
2	Calorific value 1 lb. of coal as fired, B.t.u. (2)								
3	" " " " dry coal (2)								
4	" " " " combustible (2)								
5	Time	8:00	8:30	9:00	5:00	5:30	6:00	Total	Average
6	Weight of coal, lb. (3)								
7	Weight ashes and refuse, lb.								
8	Feed water meter, cu. ft. or lb.							(4)	
9	Feed water temp, deg. F.								
10	Steam press. gage, lb. per sq. in.								
11	Percent moisture in steam or deg. superheat								
12	Flue gas temperature								
13	Draft in furnace in. of water								

(1) This is the total moisture in the coal as found by drying it artificially.

(2) This value is obtained by means of the bomb calorimeter and can be assumed from previous tests.

(3) If new fire is started weight of wood used should be multiplied by 0.4 to give equivalent weight in coal.

(4) Corrected for difference in gage glass readings at start and finish of test.

In making a combined boiler, grate and furnace test for efficiency based on coal as fired all that is necessary, is simply to weigh the coal, read the feed water meter, the feed water temperature and the pressure gage. These readings should ordinarily be taken every 30 min., although for sudden fluctuations and for special tests, 15 min. readings may be advisable. The percentage of moisture in the steam can be recorded three or four times in the course of the test by testing with a throttling or separating calorimeter and the degree of superheat, if the boiler contains superheating surfaces, is similarly obtained by the use of a thermometer in a thermometer-well.

It is expected that the boilers will be tested regularly so that data relative to the size of the grate and water-heating areas are not shown on the log sheet, but are shown, instead, on the summary sheet from which they can be transferred for later tests to succeeding summary sheets. Similarly, description of the kind of coal is omitted from the log sheet, although where the coal is subject to appreciable variation in quality (due for instance to unsettled operating conditions in the coal industry) it is important that the name of the particular coal used for the test be noted on the log. In any case this item must be recorded on the summary sheet.

Using the results tabulated in lines 5 to 13 right hand side of the test log sheet and general data as to the size and kind of coal, area of grate and of water-heating surfaces, the summary sheet is laid out.

It should be noted that the various summary items have been grouped under headings such as "General Data," "Total Quantities," "Hourly Quantities," "Efficiencies," etc., so that if information concerning efficiencies only, for instance, is desired, it is necessary to go through only such computations as are listed in the section on efficiences.

A graphical arrangement by means of which the interrelationship of some of the important items can be seen at a glance is shown in Fig. 1. Beginning at the top of the chart with combined efficiency of boiler, furnace and grate, each item is divided into its factors, and any item is equal to the value of those immediately beneath it and which would be included between two vertical lines drawn downward from the left and right

BOILER TEST SUMMARY
Data and Results of Evaporative Test
General Data

Made by.....on.....boiler,
to determine .....
Item
(a) Kind of fuel (also name of mine, etc.).....
(b) Kind of furnace.....
(c) Grate surface.....sq. ft.
(d) Water heating surface.....sq. ft.
(e) Superheating surface.....sq. ft.

Total Quantities

Item No.		Results from	Data
1	Date of trial.....	Test log	
2	Duration of trial.....	Test log, line 5	.....hr.
3	Weight of coal as fired.....	Test log, line 6	.....lb.
4	Percentage of moisture in coal	Test log, line 1	....per cent
5	Total weight of dry coal consumed	Item 3 × (1 — Item 4)	.....lb.
6	Total ash and refuse.....	Test log, line 7	.....lb.
7	Percentage of ash and refuse in dry coal.....	Item 6 ÷ Item 5	....per cent
8	Total weight of water fed to boiler	Test log, line 8	.....lb
9	Water actually evaporated, corrected for moisture or superheat in steam.....	Item 8 × Factor of Correction (1)	.....lb.
9A	Factor of evaporation.....	See foot note (2)	
10	Equivalent water evaporated into dry steam from and at 212 deg. F.....	Item 9 × Item 9A	.....lb.

[1] Factor of correction for quality of steam. When moisture is less than 2 per cent, deduct percentage from weight of water fed, thus:

$$f_1 = 1 - \frac{\text{per cent moisture}}{100}$$

For larger percentage of moisture:

$$f_1 = 1 - P\frac{H - h_1}{H - h}$$

in which
P = Proportion of moisture.
H = Total heat of 1 lb. saturated steam.
h_1 = Heat in water at temperature of saturated steam.
h = Heat in water at temperature of feed water.
For superheated steam:

$$f_1 = \frac{H_s - h}{H - h}$$

in which
H_s = Total heat in 1 lb. of superheated steam at observed temperature and pressure.
For superheated steam, factor of evaporation and correction may be combined:

$$f_3 = \frac{H_s - h}{970.4}$$

[2] Factor of evaporation $f_2 = \frac{H - h}{970.4}$ in which H and h are, respectively, the total heat in steam of the average observed pressure, and in water of the average observed temperature of the feed.

Hourly Quantities

Item No.	Description	Results from	Data
11	Dry coal consumed per hour	Item 5 ÷ Item 2	.....lb.
12	Dry coal per sq. ft. of grate surface per hour	Item 11 ÷ Item c	.....lb.
13	Water evaporated per hour corrected for quality of steam	Item 9 ÷ Item 2	.....lb.
14	Equivalent evaporation from and at 212 deg. F. per hour	Item 10 ÷ Item 2	.....lb.
15	Equivalent evaporation per hr. per sq. ft. of water heating surface	Item 14 ÷ Item d	.....

Average Pressures, Temperatures, Etc.

Item No.		Results from	
16	Steam pressure by gage, lb. per sq. in.	Test log, line 10	.....
17	Temperature of feed water entering boiler	Test log, line 9	.....deg.
18	Temperature of escaping gases from boiler	Test log, line 12	.....deg.
19	Force of draft in furnace, in. of water	Test log, line 13	.....
20	Percentage of moisture in steam or number of degrees superheating	Test log, line 11	.....

Horsepower

Item No.		Results from	
21	Horsepower developed	Item 14 ÷ 34.5	.....hp.
22	Builder's rated horsepower	From plant ledger	.....hp.
23	Percentage of builder's rated horsepower developed	Item 21 ÷ Item 22	....per cent

Economic Results

Item No.		Results from	
24	Water actually evaporated corrected for moisture, etc., per lb. of coal as fired	Item 9 ÷ Item 3	.....lb.
25	Equivalent evaporation per lb. of coal as fired	Item 10 ÷ Item 3	.....lb.
26	Equivalent evaporation per lb. of dry coal	Item 10 ÷ Item 5	.....lb.
27	Equivalent evaporation per lb. of combustible burned	Item 10 ÷ (Item 5 — Item 6)	.....lb.

Efficiency

		Results from	
28	Calorific value of 1 lb. of coal as fired by calorimeter	Test log, line 2	.....B.t.u.
29	Calorific value of 1 lb. dry coal by calorimeter	Test log, line 3	.....B.t.u.
30	Calorific value of 1 lb. of combustible by calorimeter	Test log, line 4	.....B.t.u.
31	Efficiency of boiler and furnace (based on combustible)	100 × Item 27 × 970.4 ÷ Item 30	....per cent
32	Combined efficiency of boiler, furnace and grate (based on coal as fired)	100 × Item 25 × 970.4 ÷ Item 28	....per cent
33	Combined efficiency of boiler, furnace and grate (based on dry coal)	100 × Item 26 × 970.4 ÷ Item 29	....per cent

Cost of Evaporation

Item No.		Results from	
34	Cost of coal per ton of..... lb. delivered in boiler room	From coal records	$.....
35	Cost of coal required for evaporating 1000 lb. of water from and at 212 deg.	(1000×Item 34) ÷ (Item 25× No. of lb. per ton)	$.....

extremities of the rectangle inclosing the items above. The chart indicates which items are relevant and those irrelevant to the computation required to derive any particular information desired. It also points out by reading from bottom to top how far in the analysis of the boiler performance we are able to proceed if we possess certain data, hence the instruments by which to secure any desired results.

Items 11 to 15, 21 to 23 and 34 and 35 give data which are useful in comparing the boiler installation with others as regards percentage of rated power developed, capacity per hour, and the corresponding cost of coal. Such data is especially valuable in making recommendations for new equipment, in placing responsibility for poor results and for encouraging good work on the part of the individual boiler room employes, who are

PUMP TEST LOG, SHORT FORM

Made by..... on.....pump. Date.....

Item		General Information			
	Steam Cylinder	Area piston sq. in.		Area piston rod	sq. in.
A		Net area piston=(Area piston-1/2 area piston rod) =			sq. in.
L		Length of stroke =			ft.
N		No. of single strokes per min. (a forward and backward movement = 2 strokes)			
H		Difference in elevation between water levels in supply tank and discharge opening (2)			ft.
		Temp. of water Deg.F.		Steam Pressure	lb.
		Specific Data			
		Time	cu.ft. lb. or gal. water delivered	Mean effective press. steam cyl.	
		8:00			
		8:15			
		10:00			
Item		T	W		Remarks
		Elapsed Time hrs.	Total Water	Total	
				No. of readings	
				Average	

(1) If rod extends through both cylinder heads.

Av. area = area piston − area piston rod.

For a duplex pump multiply by 2.

(2) When gages are used to measure the pressures, the difference in their readings should be entered here, if water comes to the pump under head; if under vacuum, the inches of mercury should be reduced to pounds and added to the other head. In either case the difference in elevation between the center of the gage on the discharge line and the point where the suction gage is attached should be added to the total of these readings.

able to see the results of their work from day to day, by graphic charts which make use of the above data.

Pump Efficiency Tests

In the final analysis, the efficiency of a pump is measured by its output for a given period as compared with the input of power during the same interval, or,

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

The output of the pump is determined by measuring the head and the cubic feet or gallons of water pumped. The input is shown by a steam indicator on reciprocating pumps, by a dynamometer on belt-driven pumps, and by a watt-meter used with the efficiency curve of the motor if it be a direct-connected, motor-driven pump. Collecting the data during a test may be done on a form similar to that under the heading Pump Test Log, Short Form which will be found convenient for keeping the record of a simplified efficiency test of a reciprocating steam-driven pump.

The test summary, short form shown contains five

items; the source of the information required is shown in the third column and the steps leading to the computing of the efficiency are plainly indicated. If the water delivered per hour cannot be measured in the usual way by means of tanks, barrels, calibrated orifices or water meter, it can be computed from the displacement of the plunger multiplied by the assumed volumetric efficiency expressed as a decimal fraction which may be assumed as 88 for deep well pumps, 85 for ordinary pistons, 80 for small pistons, 80 for triplex, 80 for large centrifugal, 60 for medium centrifugal and 40 for small centrifugal pumps.

Even if a test is conducted along lines necessary to secure the data shown in the preceding forms, its usefulness is limited inasmuch as the resulting information is not sufficiently detailed to enable the engineer to localize the losses so that remedies may be intelligently applied to the troubles in different elements which go to make up the pumping system.

For the purpose of discovering such weak points in a pumping installation it is best to separate the losses into volumetric, hydraulic and mechanical, and to calculate the efficiencies known by the same names which combined make up the total efficiency of the pump.

Log and summary sheets shown under the heading, Steam Pump Efficiency Test Log and Steam Pump Efficiency Test Summary

PUMP TEST SUMMARY—SHORT FORM

Item	Description	Results from	Data
	Output		
1	Weight[1] water del. per hr.	Item W log sheet / Item T log sheet	.....lb.
2	Total head pumped against	Item H log sheet	.....ft.
3	Water horsepower	Item 1 × Item 2 / 1,980,000	.....hp.
	Input		
4	Steam horsepower	Items PLAN log sht. / 33,000	.....hp.
5	Total efficiency	Item 3 / Item 4	.....per cent

[1] Reduce gallons to pounds by multiplying by 8.33. Reduce cubic feet to pounds by multiplying by 62.35.
[2] If pressure head has been read in pounds per square inch, it should be converted to equivalent head in feet by multiplying by 2.31.

STEAM PUMP EFFICIENCY TEST LOG

Made by..... on pump No..... Date.....

Line No.	Description								Enter as Item No.
a	Description of pump tested								10
b	Average length of stroke, in.								
c	Vertical dist. bet. suction gage connection and center of gage on delivery pipe ft. in.								16
						Total	Average	Equiv. head	
1	Time	8:00	8:15		9:45	10:00				3
2	Lb. (4), cu. ft. or gal. pumped							(5)		18
3	No. of single (6) strokes per min.									11
4	Temp. of water deg. F.									12
5	Steam pressure lb. per sq. in.									13
6	Delivery pressure head in discharge main lb. per sq. in.							(2)		14
7	Suction head lb. per sq. in. or in. mercury							(2) (3)		15
8	Mean eff. pressure steam cyl., lb. per sq. in. (1)									24
9	Mean eff. pressure (1) water cyl, lb. per sq. in.									25

(1) From indicator cards
(2) To change pressure head in pounds to head in feet multiply reading in pounds by 2.31.
(3) To change pressure or suction head in inches mercury to head in feet multiply reading in inches by 1.132.
(4) Meter reading.
(5) Average quantity pumped per hour (reduce gallons to pounds by multiplying by 8.33. Reduce cubic feet to pounds by multiplying by 62.36)
(6) A stroke is the movement in one direction of the piston; a forward and backward movement constitutes two strokes or one revolution.

STEAM PUMP EFFICIENCY TEST SUMMARY

Summary for single cylinder pump only. For duplex pump, multiply by 2 items 6, 9 and 11; other items accordingly.

Item No.	Description	Results from	Data
1	Made by.....on.....pump	Test log	.....
2	Date of trial	Test log	.....
3	Duration of trial	Test log line 1	.....hrs.
4	Area of steam cylinder (D = diameter in.)	$D^2 \times .7854$	.....sq. in.
5	Area of piston rod (d = diameter in.)	$d^2 \times .7854$	.....sq. in.
6	Net effective area of piston	Item 4 — Item 5 / 2 [1]	.....sq. in.
7	Area of water plunger, (D_1 = diameter in.)	$D_1^2 \times .7854$	.....sq. in.
8	Area of plunger piston rod (d_1 = diameter in.)	$d_1^2 \times .7854$	.....sq. in.
9	Net effective area of plunger piston	Item 7 — Item 8 / 2	.....sq. in.
10	Average length of stroke[2]	Test log, line b	.....ft.
11	Average No. of single strokes per minute	Test log, line 3	.....
12	Temperature of water	Test log, line 4	.....deg. F.
13	Steam pressure	Test log, line 5	lb. per sq. in.
14	Delivery head in discharge main	Test log, line 6	.....ft.
15	Suction head or amount vacuum	Test log, line 7	.....ft.
16	Pump head	Test log, line c	.....ft.
17	Total head	Items (14 + 16 + 15)	.....ft.
18	Weight of water actually delivered per hr.	Test log, line 2 ÷ Item 3	.....lb.
19	Plunger displacement per hour (computed)	Item 9 / 144 × Item 10 × Item 11 × 60	.....cu. ft.
20	Weight of water by plunger displacement per hr.	Item 19 × 62.4 [3]	.....lb.
21	Volumetric efficiency	Item 18 / Item 20 × 100	.....per cent
22	Slip of pump	100 — Item 21	.....per cent
23	Capacity, water delivered per 24 hr.	Item 18 × 24 × .12	.....gal.
24	Mean effective pressure steam cyl.	Test log, line 8	lb. per sq. in.
25	Mean effective pressure, water cyl.	Test log, line 9	lb. per sq. in.
26	Indicated horsepower, steam cylinder	Item 24 × Item 10 × Item 6 × Item 11 ÷ 33,000	.....hp.
27	Indicated horsepower, water cylinder	Item 25 × Item 10 × Item 9 × Item 11 ÷ 33,000	.....hp.
28	Mechanical efficiency	Item 27 / Item 26 × 100	.....per cent
29	Hydraulic efficiency	See footnote[4]	.....per cent
30	Total efficiency	Item 21 × Item 28 × Item 29	.....per cent

[1] For use when rod does not extend through both cylinder heads; if it does, use Item 4 — Item 5.
[2] Reduce inches to decimals of a foot by dividing by 12.
[3] Instead of 62.4, use weight of water per cu ft. corresponding to temperature.
[4] To compute hydraulic efficiency, multiply Item 17 by the pressure due to 1 ft. head of water at temperature given in Item 12 and divide this quantity by Item 26. Multiply result by 100 to get per cent efficiency.

ciency Test Summary when properly filled out give all the information necessary for the computation and segregation of these various kinds of pump efficiency. The various columns should be footed and the results transferred opposite corresponding items on the summary sheet as indicated at the bottom of the log sheet.

Data in the third column on the summary sheet, headed "results from" show in a concise way just how the results in the fourth column are figured. Whenever possible, approximate values of the items are given in the last column.

Power driven pump tests are recorded in a manner similar to that shown in the preceding. Instead of taking a reading on the steam cylinder, a dynamometer is used to record the power consumed in a belt-driven pump. A wattmeter used in connection with an efficiency curve will function similarly in the case of a direct connected motor driven pump.

Heater Tests

In the case of feed water heaters using exhaust steam, the purpose is to raise the temperature of the

HEATER TEST LOG SHEET

Made by_____ Date_____

Line No.								
	Plant Number of heater							
	Type, open - Number of trays Size " " Closed - Material in tubes Form of " Size of " Heating surface							
	Radiating Surface Kind of insulation Thickness of "							
1	Time	8:00	8:15	8:30	8:00		Total of Readings	Average
	Temperatures							
2	Temp. Inlet Water							
3	Temp. Outlet Water							
4	Temp. Steam at inlet							
5	Temp. Condensate at outlet (closed heater)							
6	Temp. Air							
7	Temp. Inside heater shell							
8	Lb. Water to heater							
9	Lb. Water from heater (open heater)							
9a	Lb. condensate (closed heater)							

water to a point just below boiling. As the plant usually has more exhaust steam than can be used to heat the water for boiler feed purposes only, considerably more steam goes through the heater than is needed unless it is of induction type and it would seem unjust to compare the operation of heaters of this class according to their efficiencies based on the heat output divided by the heat input.

Where exhaust steam can be used for other purposes, however, or the amount is inadequate for feed water heating it is well to have some way of checking up the performance of the heater to make sure that the heat transfer therein goes to the water rather than an excessive amount to radiation, also that the heater is of sufficient size to perform the work required.

This may be done by noting inlet and outlet water temperatures, amount of water heated, temperature of exhaust steam which may be considered dry after passing through an oil separator and temperature of condensate. The radiation which can be expected from the surface of the heater can be estimated when the exposed surface, kind and thickness of insulation and the temperature difference between the inside and outside of the heater are known.

With this information at hand it is possible to make

HEATER TEST SUMMARY SHEET

Item	Description	Results from	Data
1	Mean temperature increase of water	Test log, line 3 — line 2	.....deg. F.
2	Lb. water per hour	Test log, line 8 ÷ line 1	.....lb.
3	Heat transfer per hour	Item 2 × Item 1	.....B.t.u.
4	Temperature difference between inlet steam and outlet water	Test log, line 4 — line 3	.....deg. F.
5	Heat value of 1 lb. entering steam	Steam Tables	.....B.t.u.
6	Heat liberated by 1 lb. steam	Item 5 × (line 3 or line 5 — 32)	.....B.t.u.
7	Heat given up by steam per hour	Item 6 × line 9a of test log ÷ line 1	.....B.t.u.
8	Loss by radiation per hour (induction type heater)	Item 7 — Item 3	.....B.t.u.

comparisons between performances of the heater at various times which is of considerable value where varying conditions exist.

Economizer Efficiency Tests

As a rule testing of the economizer is done in conjunction with the test for combined boiler, furnace and grate efficiency. This follows because the combustion of the fuel constitutes an important item in the computations, and inasmuch as this also is a large factor in the making of a boiler test, it is usually found advantageous to combine the two tests in one.

Here again, as with heaters, comparison of efficiencies computed on the heat output divided by the heat input basis is of little or no value as it is well recognized that the economizer is purely a saving device and can utilize only such heat as working conditions of the plant can spare. In order therefore that the work of an economizer from time to time may be compared it is well to

ECONOMIZER TEST LOG

Made by_____ on economizer No._____ Date_____

Line No.	Description						Total	Average	Enter as Item No.
a	Description of economizer B.t.u. per pound of coal (1)								Part of 1
	Time	8:00	8:20		9:40	10:00			
2	Weight of coal burned, lb.								Part of 1
3	CO_2 by volume in flue gas, percent								2
4	Temp. of flue gas at entrance, deg. F.								Part of 5
5	Temp. of flue gas leaving, deg. F.								Part of 5
6	Water meter (2) reading, cu. ft. or lb.								7
7	Temp. of water at entrance, deg. F.								Part of 8
8	Temp. of water leaving, deg. F.								Part of 8

1 From Government bulletin, from proximate or ultimate analysis (see discussion under "Coal Records")

2 Convert cubic feet to pounds by multiplying cubic feet by 62.35.

compute the heat absorbing ratio from tests which will give a check upon the operation.

Measurement of the heat conveyed to the feed water is accomplished by taking temperature readings of the water at entrance and outlet, and by recording the quantity of water by water meters, by weighing the water in barrels or, provided all the water can be accounted for

ECONOMIZER TEST SUMMARY—SHORT FORM

Item	Description	Results from	Data	Approx. Value
1	Coal burned per 10,000 B.t.u.'s	Test log, Line 1 × Line 2 ÷ 10,000	.....B.t.u.	1.35 × lb. of coal
2	Average CO_2 by volume	Test log, line 3	..per cent	15 excellent
3	Weight of gas per 10,000 B.t.u. in coal	Use Item 2 with values in Table II	.....lb.	28 poor 19 fair 10 excellent
4	Total weight of flue gases	Item 1 × Item 3	.....lb.	
5	Average temp. difference between inlet gases and inlet water.	Test log, line 4 — line 7	...deg. F.	About 250 to 300 deg.
6	Heat of inlet gases above inlet temperature of water	Item 4 × Item 5 × .23	.....B.t.u.	
7	Feed water passing through economizer	Test log, line 6	.....lb.	
8	Average increase feed water temperature	Test log, line 8 — line 7	...deg. F.	About 100 deg.
9	Total heat absorbed by feed water	Item 7 × Item 8[1]	.....B.t.u.	
10	Absorption ratio of economizer	Item 9 ÷ Item 6	.....	

1 For a greater degree of refinement the B.t.u.'s in water corresponding to the two temperatures should be used to compute the B.t.u. gain per pound of water; this multiplied by Item 7 will give the total heat absorbed.

by evaporation, by measuring the condensate from the engines or turbines.

The amount of heat available in the flue gases is based on their weight and temperature. Determining the weight of the flue gases presents a complete problem; it includes within itself, when accurate results are demanded, an analysis of the fuel burned and the determination of the volume and analysis of the gaseous products of combustion. As the quantity of air consumed in the burning of the coal is of necessity not included in a chemical analysis of the coal itself, it follows that some other method must be used to ascertain its volume; for this the CO_2 recorder, or Orsat apparatus, is employed.

For work which does not require precision a fairly close approximation of the weight of gas is based on the boiler horsepower and is given by the following formula:

$$W = \frac{33{,}480w}{10{,}000\ (E + .02)}$$

in which W = weight of gas in pound per hour per boiler horsepower,

w = weight of gas per 10,000 B.t.u. based on the CO_2 content (see Table I),

E = combined efficiency of the boiler, furnace and grate expressed as a decimal fraction.

To take care of the carbon lost in the ash 0.02 is added to the assumed efficiency.

Table II is useful in determining the weight of the gases of combustion. Values are dependent on the percentage of CO_2 shown by a CO_2 recorder, and on the combined efficiency of the boiler, furnace and grate which can be assumed for approximate results or, for more accurate work, can be determined by test.

ECONOMIZER TEST LOG, EXTENDED FORM

Made by_____ on economizer No._____ Date_____

Coal Sample Analysis		
Line	Component, etc.	per cent
a	Carbon (C)	
b	Hydrogen (H_2)	
c	Oxygen (O_2)	
d	Sulphur (S)	
e	Nitrogen (N_2)	
f	Ash	
g	B. t. u. per pound coal	

Flue gas analysis		
Line	Component	per cent
h	Nitrogen (N_2)	
j	Carbon dioxide (CO_2)	
k	Oxygen (O_2)	
m	Carbon monoxide (CO)	

Line No.	Description							Enter as Item No.
n	Description of economizer							
	Time	8:00	8:20	9:40	10:00	Total	Average	
1	Weight of coal fired, lb.							9
2	Coal lost through grate, lb.							Part of 1
3	Temp. of flue gases at entrance deg.F.							Part of 11
4	Temp. of flue gases leaving, deg. F.							Part of 11
5	Water meter reading, cu.ft. or lb. (1)							13
6	Temp. of feed water at inlet, deg. F.							Part of 14
7	Temp. of feed water at outlet, deg. F.							Part of 14

(1) Convert cubic feet to pounds by multiplying by 62.35

TABLE I. WEIGHT OF GASES AND PERCENTAGE OF EXCESS AIR CORRESPONDING TO VARIOUS PERCENTAGES OF CO_2 WHEN PERCENTAGE OF CO EQUALS ZERO

Per cent CO_2 in dry gases by vol.	18.7	18.0	17.0	16.0	15.0	14.0	13.0	12.0
Excess air in percent of theoretical minimum	0	4	10	17	24	33	43	54
Wght. of gas per 10000 B.t.u. in coal lb.	7.8	8.1	8.6	9.1	9.6	10.3	11.0	11.9
Per cent CO_2 in dry gases by vol.	11.0	10.0	9.0	8.0	7.0	6.0	5.0	
Excess air in percent of theoretical minimum	68	85	105	130	162	206	267	
Wght. of gas per 10000 B.t.u. in coal lb.	12.9	14.7	15.7	17.6	20.0	23.3	27.8	

The log and summary sheets of the economizer test short form, are designed for use when precision is not required.

A more accurate method used to determine the weight of gas per pound involves the use of the formula:

$$\text{Lb. flue gas per lb. of coal} = 3.036\,P\left(\frac{N_2}{CO_2 + CO}\right) + (1 - a)$$

in which P = carbon burned, stated as a decimal fraction of the weight of coal and is the proportion of carbon in the coal minus that in ash,

N_2, CO_2 and CO are proportions by volume of the gases in the flue gas,

And a = decimal part by weight of non-volatile residue per pound of coal.

Extended test forms for the log and summary sheets, in which the exact method of determining the weight of the flue gases as derived in the above formula is used are shown herewith. A problem involving the use of this formula is worked out in the analysis section.

TABLE II. WEIGHT OF GAS PER BOILER HORSEPOWER-HOUR AT SEA LEVEL CORRESPONDING TO VARIOUS CO_2 AND EFFICIENCY PERCENTAGES

Weight of gas per boiler hp. at sea level corresponding to various CO_2 and efficiency percentages

Percent of CO_2 in dry gases by volume	8.	8.	9	10	12	12	14	14
Assumed combined eff. of boiler grate and furnaces-	63	66.	66	68	70	75	68	78
Wght. of gases in lb. per boiler hp.	91	87	77	68	55	52	49	43

ECONOMIZER TEST SUMMARY—EXTENDED FORM

Item	Description	Results from	Data	Approx. Value
1	Percentage of coal lost through grate	100 × Test log, line 2 ÷ line 1	..per cent	5 per cent
2	Percentage of carbon in coal lost.....	Estimated	..per cent	20 per cent
3	Total carbon lost per cent of coal fired....	Item 1 × Item 2	..per cent	1 to 2 per cent
4	Percentage of coal fired burned as carbon (decimal fraction)...	Test log, line a — Item 3 (summary)	.....	.60 to .90
5	Ratio of nitrogen to CO_2 and CO in flue gas... $\frac{N_2}{CO_2 + CO}$	Test log, lines h, k and m		
6	Lb. air supplied per lb. of coal	3.036 × Item 4 × Item 5	.....lb.	
7	Gas constituents of 1 lb. of coal.....	1.00 — per cent non volatile matter in coal (Test log)	.....lb.	.88 lb. to .95 lb.
8	Total weight flue gas from 1 lb. of coal....	Item 6 + Item 7	.....lb.	
9	Weight of coal as fired	Test log, line 1	.....lb.	
10	Total weight of gases generated	Item 8 × Item 9	.....lb.	
11	Average temp. difference between inlet gases and inlet water.....	Test log, line 3 — line 6	...deg. F.	
12	Total heat of inlet gases above inlet water temperature...	Item 10 × Item 11 × 0.23	....B.t.u.	
13	Weight water through economizer	Test log, line 5	.....lb.	
14	Average temp. water at outlet	Test log, line 7	...deg. F.	
14a	B.t.u. in water at outlet per lb.....	Steam Tables	....B.t.u.	
15	Average temp. water at inlet	Test log, line 6	...deg. F.	
15a	B.t.u. in water at inlet per lb.....	Steam Tables	....B.t.u.	
16	Average heat absorbed by water.....	Item 14 — Item 15	.....B.t.u. per lb.	
17	Total heat gained by water	Item 13 × Item 16	....B.t.u.	
18	Economizer absorption ratio	Item 17 ÷ Item 12		

Steam Engine Efficiency Tests

Steam engine efficiency as expressed by the relation between the power shown by a brake and the indicated horsepower is commonly termed mechanical efficiency and is expressed by the formula:

$$Em = \frac{\text{b. hp.}}{\text{i. hp.}}$$

in which b. hp. is brake horsepower and i. hp. is indicated horsepower.

Data for a mechanical efficiency test comprise brake readings and the making of a set of indicator cards every 10 or 20 minutes. It will be observed that once the engine and brake constants are determined, the only test data necessary for subsequent trials will consist of readings of gross weight on brake, the revolutions per minute, and indicator cards from the head and crank ends of the cylinders.

In the case of large engines it is sometimes not feasible to obtain the brake horsepower directly. Therefore the engine is run light; that is, without any connected load and a "friction indicator diagram" obtained in the same way as the ordinary indicator card, which will show approximately the amount of work done by the engine in overcoming frictional resistance. The difference between the indicated horsepower showing of the engine running under load and running light is then considered the brake horsepower, although with some error due to the fact that the friction load is greater when the engine is running loaded than when unloaded.

The results obtained in conducting a test along the lines just described give merely the efficiency of the engine as a machine. In a majority of cases this information will not suffice, as it is desirable to know just what the engine is doing in respect to its consumption of steam. Therefore we are showing a complete form of engine efficiency test, patterned after the A. S. M. E. codes of 1912 and 1915, which will give an excellent line on the heat or thermal efficiency of the engine, along with data relative to its mechanical efficiency.

The log sheet comprises a series of readings at intervals of 20 min., covering observations of steam and barometric pressure, vacuum and temperatures. Besides these the quantities of steam delivered to the engine or the amount of condensed steam and the condenser leakage and the moisture content in the steam are noted as shown under "Quantities, steam and condensate."

Indicator diagram readings with corresponding r.p.m. and weights on the brake comprise the third section of the log sheet. If it is not possible during the test to examine the cards to determine the values of the commercial cut-off, initial pressure, etc., this can be done when convenient; but the tester must not fail properly to mark each card, placing thereon the time of day when taken, the number of cylinder and the end of cylinder.

Turning to the summary sheet we find it divided into sections comprising: (1) dimensions and constants, containing data which, once determined, can be used for all succeeding tests of the engine; (2) pressures and temperatures, (3) total quantities, (4) hourly quantities, (5) indicator diagrams, (6) speed and power, (7) economy results, (8) efficiency results, and two minor sections.

The second and third sections are made up largely of footings taken directly from the log sheet.

From the total quantities, the hourly quantities and hourly heat data are derived, as shown in the columns headed "results from." Heat consumption of the engine

STEAM ENGINE, GENERAL HEAT AND MECHANICAL EFFICIENCY TEST LOG SHEET

Engine_____ Tested by_____ Date_____

Line No.	Description								Enter as Item No.
	Description of Engine								
1	TIME	8:00	8:20	13:40	1:00	Total	Reading	Average	5
2	Pressure in steam pipe near throttles by gage, lb. per sq. in.								8
3	Barometric pres. of atmosphere in in. of mercury								9
4	Pressure in receiver by gage lb. per sq. in.								10
5	Vacuum in condenser in. of mercury								11
6	Press. in exhaust pipe near engine by gage lb. per sq. in.								12
7	Press. in jackets and reheaters lb. per sq. in.								13
8	Temp. of steam near throttle deg. F.								14
9	Temp. of steam in exhaust pipe near engine								15
10	Steam Meter Reading								16
11	Steam Condensate lb.								17
12	Condenser leakage lb.								17
13	Moisture in Steam per cent								18
	1st Cyl.								
14	Commercial cutoff percent of stroke								23
15	Initial pressure above atmosphere lb. per sq. in.								24
16	Back press. at lowest point above or below atmosphere								25
17	Area of indicator diagram sq. in. ÷ Length of Card								26
	2nd Cyl.								
18	Commercial cutoff percent of stroke								23
19	Initial pressure above atmosphere lb. per sq. in.								24
20	Back press. at lowest point above or below atmosphere								25
21	Area of indicator diagram sq. in. ÷ Length of Card								26
22	r.p.m.								27
23	Gross weight in brake lb.								30

is found by taking the quantity of steam consumed and multiplying by the total heat in 1 lb. of steam at the throttle pressure (Item 8), less the heat in 1 lb. of water at the throttle pressure (Item 15) in the exhaust pipe near the engine.

The thermal efficiency of the engine (Item 35); that is, the proportion of the total heat consumption which is converted into work, is found by dividing 2546.5 (the

STEAM ENGINE, GENERAL HEAT AND MECHANICAL EFFICIENCY TEST SUMMARY

(1) Dimensions and Constants

Item

1 Engine No.....Tested by.....Date.....
2 To determine .....
3 Duration, hours, and decimal parts[1] (Col. 1 test log).....
4a Type of engine (Simple or mult. expansion).....
4b Class of service (mill, electric, etc.).....
4c Auxiliaries, steam or electric driven (condenser, oil, pump, etc.) .....
4d Rated power of engine.....hp.....
5 Main engine data.....

		1st Cyl. Head	1st Cyl. Crank	2nd Cyl. Head	2nd Cyl. Crank
5a	Dia. piston, in.....	.....	.....	.....	.....
5b	Area, sq. in.....	.....	.....	.....	.....
5c	Dia. piston rod, in.....	.....	.....	.....	.....
5d	Area, sq. in.....	.....	.....	.....	.....
5e	Net eff. area sq. in. (A)[2]....	.....	.....	.....	.....
5f	Stroke of piston, ft. (L).....	.....		.....	
5g	Clearance (average) in per cent of piston displacement.....	.....		.....	
5h	Cylinder ratio based on net piston displacement	.....		.....	

6 Engine constant for 1 lb. m. e. p. and 1 r. p. m. $= \dfrac{2 \times \text{Item 5e} \times \text{Item 5f}}{33{,}000} =$

7 Brake constant $\dfrac{2 \times 3.1416 \times r}{33{,}000}$ r = length of brake arm in feet.....

7a Tare of brake.....lb.....

(2) Average Pressures and Temperatures

Item	Description	Results from	Data
8	Aver. press. in steam pipe near throttle by gage.....	Test log, line 2	.....lb. per sq. in.
9	Aver. barometric press. of atmosphere in in. of mercury	Test log, line 3	.....in.
10	Av. pressure in receiver by gage	Test log, line 4	...lb. per sq. in.
11	Av. vacuum in condenser in in. of mercury.....	Test log, line 5	.....in.
12	Av. press. in exhaust pipe near engine, by gage.....	Test log, line 6	lb. per .....sq. in.
13	Av. press. in jackets and reheaters, by gage.....	Test log, line 7	.....deg. F.
14	Av. temperature of steam near throttle.....	Test log, line 8	.....deg. F.
15	Av. temperature of steam in exhaust pipe.....	Test log, line 9	.....deg. F.

(3) Total Quantities

Item	Description	Results from	Data
16	Total steam to engine.....	Test log, line 10	.....lb.
17	Total condensed steam from surface condenser.....	Line 11 — line 12 test log	.....lb.
18	Factor of correction for quality of steam.....	Line 13 and footnote[3]	.....per cent
19	Total dry steam consumed by engine	Item 16 or 17 corr. by Item 18	.....lb.

(4) Hourly Quantities

Item	Description	Results from	Data
21	Total dry steam consumed by engine per hour.....	Item 19 ÷ Item 3	.....lb.
22	Heat units consumed by engine per hour.....	Item 21 × total heat of steam at pressure of Item 8 — heat in 1 lb. of water at temp. of Item 15	.....B.t.u.

[1] Reduce minutes to decimal parts of an hour by dividing by 60.
[2] Net effective area "A" for each side of the piston equals the area of the piston when the rod does not extend through it on the face in question, but is equal to the difference between areas of piston and rod when the latter does extend through the face.
[3] Factor of correction for quality of steam: When moisture is less than 2 per cent, deduct percentage from weight of water fed, thus:

$$f_1 = 1 - \frac{\text{per cent moisture}}{100}$$

For larger percentage of moisture:

$$f_1 = 1 - P\frac{H - h_1}{H - h}$$

in which
P = Proportion of moisture.
H = Total heat of 1 lb. saturated steam (see steam tables).
h_1 = Heat in water at temperature of saturated steam.
h = Heat in water at temperature of feed water.

(5) Indicator Diagrams

		Results from	Data 1st Cyl.	Data 2nd Cyl.
23	Av. commercial cut-off in per cent of stroke	Lines 14 and 18	..per cent	..per cent
24	Av. initial pressure above atmosphere	Lines 15 and 19	lb. per ....sq. in.	lb. per ....sq. in.
25	Av. back pressure at lowest point above or below atmosphere	Lines 16 and 20	lb. per ....sq. in.	lb. per ....sq. in.
26	Mean effective pressure	Lines 17 and 21 × scale of spring	lb. per ....sq. in.	lb. per ....sq. in.

(6) Speed and Power

Item	Description	Results from	Data
27	Revolutions per minute	Test log, line 22	.....r.p.m.
28	Piston speed	Item 27 × Item 5f × 2	..ft. per min.
29	Indicated horsepower developed by main engine cylinders	Item 26 × Item 27 × Item 6	.....i.hp.
30	Brake horsepower	(Test log, line 23 + Item 7a[4]) × Item 27 × Item 7	.....br. hp.

(7) Economy Results

Item	Description	Results from	Data
31	Dry steam consumed by engine per i. hp.-hr.	Item 21 ÷ Item 29	.....lb.
32	Dry steam consumed by engine per br. hp.-hr.	Item 21 ÷ Item 30	.....lb.
33	Heat units consumed by engine per i. hp.-hr.	Item 22 ÷ Item 29	.....B.t.u.
34	Heat units consumed by engine per br. hp.-hr.	Item 22 ÷ Item 30	.....B.t.u.

(8) Efficiency Results

		Results from	Data
35	Thermal efficiency of engine referred to i. hp.	2546.5 × 100 ÷ Item 33	.....per cent
36	Thermal efficiency of engine referred to br. hp.	2546.5 × 100 ÷ Item 34	.....per cent

(9) Work Done Per Heat Unit

37	Net work per B.t.u. consumed by engine	1,980,000 ÷ Item 34	.....ft-lb.

(10) Sample Diagram

38	Sample diagrams from each cylinder		

[4] Whether the tare of the brake, Item 7a, is to be added or subtracted to obtain the net weight depends on the weighing mechanism itself.

B.t.u. equivalent of one horsepower-hour) by the number of heat units actually consumed per horsepower-hour.

To facilitate the use of the efficiency data sheets a graphic layout has been made which shows at a glance the inter-relationship of the various factors comprising the engine efficiency data. The particular items which have been selected for this purpose are chosen for their effectiveness in pointing out the many advantages which obtain in the use of such a chart; other items, provided they bear a definite relationship to each other (shown in the third column of the various summary sheets), could be used equally well.

Briefly, then, beginning at the top of the sheet, in this case Item 35, each item is divided into its factors, the quotient appearing immediately above the dividend and divisor, which are placed side by side with the division sign between them, and the product immediately above the multiplicand and multiplier or multipliers, which are side by side, with the sign of multiplication between.

Similarly, beginning at the bottom with data collected in the running of the test and entered on the log sheet, working up to the top of the page, these data by addition, subtraction, multiplication or division merge into items which become more and more inclusive, until the one uppermost is reached.

Again, any item is equal to the value of the items immediately beneath it, as shown by the horizontal brackets, and which would be included between two vertical lines drawn downwards on the chart from the left and right extremities of the rectangle enclosing the items.

Another exceedingly valuable function of the chart is to point out how far in the analysis of the engine performance we are able to proceed if we possess certain data, and, correlatively, the instruments by which to secure them.

This method of analysis giving, as it does, information as to what we must have, and showing what is not needed, is applicable to all the items shown on the summary sheet. Thus any engineer can construct his own charts for information he is particularly interested in having, from data given in the third column, headed "results from," taking care to draw his rectangles in accordance with the principles described herein.

Steam Turbine Efficiency Tests

In many respects the steps taken in the testing of steam turbines conform to those taken in the testing of

STEAM TURBINE, GENERAL HEAT AND MECHANICAL EFFICIENCY TEST LOG SHEET

Made by..... on turbine No..... Date.....

Line No.	Description					Total	Average	Enter as Item No.
	Description of turbine							
1	Time	8:00	8:20	12:40	1:00			5
	Pressures and Temperatures							
2	Pressure in steam pipe near throttle by gage, lb. per sq. in.							6
3	Barometric pressure of atmosphere in in. of mercury							7
4	Pressure in exhaust pipe near turbine by gage, lb. per sq. in.							8
5	Vacuum in condenser, in. of mercury							9
6	Temp. of steam near throttle deg. F.							10
7	Temp. of steam in exhaust pipe near turbine, deg. F.							11
8	Percentage of moisture in steam near throttle or number of degrees superheating							12
	Quantities, Steam and Condensate							
9	Steam meter reading							13
10	Steam condensed, lb.							Part of 14
11	Condenser leakage and leakage of shaft and pump glands							Part of 14
	Speed and Power							
12	Speed, full load r.p.m.							19
13	Speed, no load r.p.m.							20
14	Fluctuation when changing from full to half load r.p.m.							21
15	Gross weight on brake, lb.							Part of 22

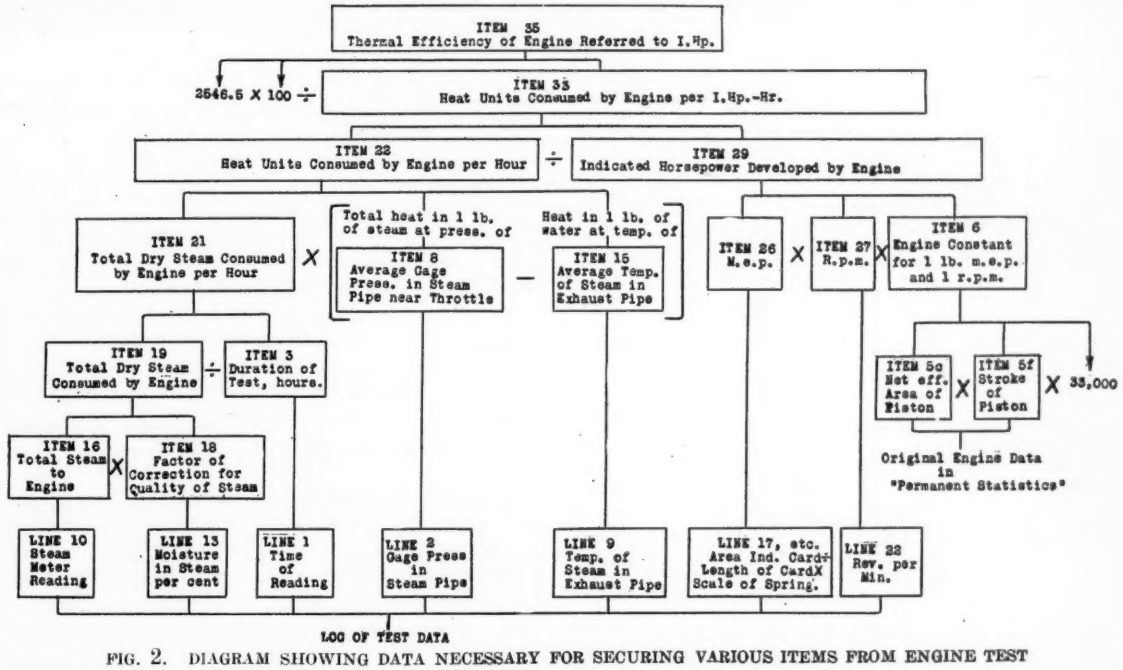


FIG. 2. DIAGRAM SHOWING DATA NECESSARY FOR SECURING VARIOUS ITEMS FROM ENGINE TEST

steam engines. For our purposes, we have in both cases eliminated consideration of the generation of electrical energy which is, in a majority of cases, accomplished by direct or semi-direct connection with the prime-mover. This enables us to test the engine or turbine, as the case may be, without resorting to the use of electrical measuring apparatus. The subject of generator testing is treated separately.

Outside of the information obtained during an engine test which has already been taken up, the following point deserves mention: If the amount of steam used is determined from the water discharged by the wet vacuum or hot-well pump, the amount so discharged should be corrected for condenser leakage, for water drawn in through the packing glands of the turbine, and for any other supplementary supply of water.

STEAM TURBINE EFFICIENCY TEST, SUMMARY

(1) Dimensions and Constants

Item No.	Description
1	Turbine No.....Tested by.....Date.....
2	To determine .....
3	Duration, hr. and decimal parts (Test log, line 1).....
4a	Type of turbine (impulse, reaction or combination).....
4b	Class of service (electric, pumping, compressor, etc.).....
4c	Auxiliaries, steam or electric drive (condensers, oil pumps, etc.) .....
4d	Rated capacity of turbine.....
4e	Capacity of generator or other apparatus consuming power of turbine .....
5	Brake constant $\frac{2 \times 3.1416 \times p}{33{,}000}$ in which "p" equals length of brake arm in ft.....
5a	Tare of brake, lb. (weight when turbine is not running).....

(2) Average Pressures and Temperatures

Item	Description	Results from	Data
6	Av. pressure in steam pipe near throttle by gage.....	Test log, line 2	lb. per .....sq. in.
7	Av. barometric pressure of atmosphere in in. of mercury	Test log, line 3	.....in.
8	Av. pressure in exhaust pipe near turbine, by gage.....	Test log, line 4	lb. per .....sq. in.
9	Av. vacuum in condenser in in. of mercury	Test log, line 5	..... in.
10	Av. temperature of steam near throttle	Test log, line 6	.....deg. F.
11	Av. temperature of steam in exhaust pipe near turbine	Test log, line 7	.....deg. F.
12	Av. percentage of moisture in steam near throttle, or number of degrees of superheat	Test log, line 8	per cent or .....deg. F.

(3) Total Quantities

Item	Description	Results from	Data
13	Total steam to turbine.....	Test log, line 9	.....lb.
14	Total condensed steam from surface condenser.....	Test log, lines 10 and 11	.....lb.
15	Factor of correction for quality of steam.....	Item 12 and footnote[1]	.....per cent
16	Total dry steam consumed by turbine	Item 13 corrected by Item 15	.....lb.

(4) Hourly Quantities

Item	Description	Results from	Data
17	Total dry steam consumed by turbine per hour.....	Item 16 ÷ Item 3	.....lb.
18	Heat units consumed by turbine per hour.....	Item 17 × (total heat of 1 lb. of steam at pressure of Item 6 — heat in 1 lb. of water at temperature of Item 8	.....B.t.u.

[1] Factor of correction for quality of steam: When moisture is less than 2 per cent, deduct percentage from weight of water fed, thus:

$$f_1 = 1 - \frac{\text{per cent moisture}}{100}$$

For larger percentages of moisture:

$$f_1 = 1 - P\frac{H - h_1}{H - h}$$

in which
P = Proportion of moisture.
H = Total heat of 1 lb. of saturated steam (see steam tables).
h_1 = Heat in water at temperature of saturated steam.
h = Heat in water at temperature of feed water.

(5) Speed and Power

Item	Description	Results from	Data
19	Revolutions per minute.....	Test log, line 12	.....r.p.m.
20	Variation of speed between no load and full load.....	Test log, line 12 — line 13	.....r.p.m.
21	Momentary fluctuation of speed on suddenly changing from full load to half load measured by the increase in the revolutions due to the change	Test log, line 14	.....r.p.m.
22	Brake horsepower.....	(Test log, line 15 + Item 5a) × Item 19 × Item 5[2]	.....br. hp.

(6) Economy Results

		Results from	Data
23	Dry steam consumed by turbine per br. hp.-hr.....	Item 17 ÷ Item 22	.....lb.
24	Heat units consumed by turbine per br. hp.-hr.....	Item 18 ÷ Item 22	.....B.t.u.

(7) Efficiency Results

25	Thermal efficiency of turbine..	2546.5 × 100 ÷ Item 24	.....per cent

(8) Work Done Per Heat Unit

		Results from	Data
26	Net work per B.t.u. consumed by turbine	1,980,000 ÷ Item 24	.....ft.-lb.

[2] When rotation tends to lift the measuring weights, the tare of the brake (effect of the weight of brake arm, band, etc., on the weights or scale when turbine is not running) is added to the measuring or scale weights to obtain the net weight used in the formula; when rotation is in the opposite direction, the tare is subtracted to get the net weight.

It is highly desirable when comparing turbines of the same size and type that test results should be reduced to a uniform standard of vacuum, superheat and admission pressure. In this way it will be possible to compare results obtained in plant efficiency tests with similar tests made at the factory.

Condenser Tests

In the case of surface condensers, a fairly satisfactory method of comparison of condenser performance

SURFACE CONDENSER TEST LOG SHEET

Made by_____ on condenser No._____ Date _____

Line No.	Description							Enter as Item No.
1	Description of Condenser							
2	Condenser Surface, sq. ft. —S =							
3	Time	8:00	8:20	9:40	10:00	Total	Average	
4	Vacuum, in. of mercury							
5	Initial temperature circulating water, deg. F.							
6	Final temperature circulating water, deg. F.							
7	Apparent Steam Condensed, lb.							
8	Condenser leakage lb.							
9	Lb. circulating water							

can be had by comparing the heat transmission through the condenser tubes.

A formula worked out by C. F. Braun (A. S. M. E. proceedings, 1915), gives the coefficient of heat transmission by the formula:

$$U = \frac{W \times Q}{M \times S}$$

In which

U = B.t.u. per sq. ft.

W = Pounds of steam condensed per hour.

Q = Total heat removed by circulating water per pound steam condensed (usually taken as 1000 in all cases for simplicity).

M = Mean temperature difference in deg. F.

S = Square feet of cooling surfaces.

The value of M, above, in terms of steam and circulating water temperature is given by the formula:

$$M = (TW_2 - TW_1) \div \text{the Naperian Log. of } \frac{TS - TW_1}{TS - TW_2}$$

in which

TW_1 and TW_2 are, respectively, the initial and final temperatures of the circulating water.

TS is the temperature of the steam, which is assumed to be constant throughout the condenser.

SURFACE CONDENSER TEST, SUMMARY SHEET

Item	Description	Results from	Data
1	Duration of test.....	Test log, line 3	.....hr.
2	Total steam condensed.....	Test log, line 7 — line 8	.....lb.
3	Steam condensed per hour (W)	Item 2 ÷ Item 1	.....lb.
4	Average initial temperature circulating water (TW_1)...	Test log, line 5	.....deg. F.
5	Average final temperature circulating water (TW_2).....	Test log, line 6	.....deg. F.
6	Difference between initial and final temperature of circulating water.....	Item 5 — Item 4	.....deg. F.
7	Average vacuum, in. of mercury	Test log, line 4	.....in.
8	Temperature of steam (TS)..	Steam tables value corresponding to Item 4	.....deg. F.
9	Difference in temperature between steam and water at initial temp.....	Item 8 — Item 4	.....deg. F.
10	Difference in temperature between steam and water at final temp.....	Item 8 — Item 5	.....deg. F.
11	Ratio of temp. difference between steam and water at initial and final temperatures	Item 9 ÷ Item 10	.....
12	Mean temperature difference in deg. F.....	Item 6 ÷ Log e Item 11	.....deg. F.
13	Pounds steam condensed per square foot per hour.....	Item 3 ÷ Test log, line 2	.....lb.
14	B.t.u. per square foot per hour	1000 × Item 13	.....B.t.u.
15	B.t.u. per sq. ft. per deg. F. diff. per hour = coefficient of heat transmission.....	Item 14 ÷ Item 12	.....B.t.u.

[1] If a table of hyperbolic logarithms is not available, the hyperbolic logarithm of any quantity (the logarithm to the base "e") can be found as follows: Find its logarithm to the base 10 (common or Briggs logarithms) and divide the logarithm so found arithmetically by 0.43430, which is the logarithm of e (2.7183) to the base 10; i. e.,

$$\text{Log}_{10}\ 2.28 = 0.35793$$
$$\text{Log}\ e\ 2.28 = 0.35793 \div 0.43430 = 0.824$$

Thus by knowing the B.t.u. transmitted per sq. ft. per degree difference per hour of two or more condensers or the same condenser at different times, their relative heat transmitting abilities can be compared, even though the temperature ranges vary considerably.

In order that this comparison may be made, the ac-

companying forms have been prepared, the log sheet giving, as in other tests considered, data necessarily collected at the time of test while the summary gives calculated data.

Generator Efficiency Tests

Testing generators apart from the prime movers necessitates the making of what is practically a laboratory test, and therefore data concerned therewith are outside the scope of our consideration at the present time. We shall therefore confine our attention to the data required in making the test of the generator as a part of a complete engine-generator or turbo-generator unit.

Thus, generator efficiency, when the power input is known, is given by the formula:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{watts}}{\text{horsepower} \times 746}$$

Input of the engine or turbine to the generator will be the brake horsepower output, usually determined by taking the difference between the indicated horsepower when running with a load and running light, or by getting the brake horsepower direct by means of a Prony or water brake. The test data needed to determine brake horsepower in either case will be found in the record of the efficiency tests of engines and turbines and will not be repeated here.

GENERATOR EFFICIENCY TEST LOG SHEET

Line	Description								
1	Made by					Date			
2	Description of generator					No.			
	volts a.c. or d.c.			phase		r.p.m.			
	a. Voltmeter No.....Correction b. Ammeter No..... " c. Power factor meter No.. "								
	Description	Percent rated load (1)							
		10	20	30	90	100	110	etc.	
3	Voltmeter reading								
4	Ammeter reading								
5	Power factor meter reading(2)								
6	Rev. per min.								
7	Brake horsepower								

(1) These are suggested percentages; the actual percentage in each trial must be determined from the data.

(2) This item not used for d.c. generators

GENERATOR EFFICIENCY TEST COMPUTATION SHEET

Item	Description	Results from[1]	Per Cent Rated Load 10 20	100 110 etc.
1	Efficiency of d.c. generator	$\frac{\text{Line 3} \times \text{Line 4}}{\text{Line 7} \times 746}$	....	....
2	Efficiency of single-phase a.c. generator	$\frac{\text{Line 3} \times \text{Line 4} \times \text{Line 5}}{\text{Line 7} \times 746}$	....	....
3	Efficiency of 2-phase a.c. generator	$\frac{2 \times \text{Line 3} \times \text{Line 4} \times \text{Line 5}}{\text{Line 7} \times 746}$	....	....
4	Efficiency of 3-phase a.c. generator	$\frac{\text{Line 3} \times \sqrt{3} \times \text{Line 4} \times \text{Line 5}}{\text{Line 7} \times 746}$	....	....

[1] Meter readings used in this column are to be gross readings corrected for meter error.

Therefore, in making up the log sheet which we show herewith, we have assumed that the brake horsepower can be determined in each case, thus giving us the input directly.

Output of the generator is tested at various percentages below and above the rated output, and the efficiencies obtained as a result are plotted to form an efficiency curve. Volt and ammeter readings (and power factor readings in the case of a.c. generators) are taken simultaneously. It must be understood that in using the formulas on the computation sheet the values to be substituted for the items which make up the formula for the efficiency at any per cent load must be those values obtained in the test for that particular per cent load.

Motor Efficiency Tests

The general idea behind a motor efficiency test is to plot an efficiency curve for various horsepower outputs of the motor in order to compare it with the efficiency curve based on the maker's guarantee. Therefore, knowing the rating of the motor at full load, as shown on the name plate, enough readings of input and output at nominal outputs above and below full load should be taken so that the efficiency curve can be properly plotted.

MOTOR EFFICIENCY TEST LOG SHEET

Line										
1	Made by_____ Date_____									
2	Description of motor tested.....hp.....volts..... .....a.c. or d.c.....phase.....r.p.m.....									
3	Tare of brake.....lb.									
4	Length "r" of brake arm.....ft. a. Voltmeter No.....Correction b. Ammeter No..... " c. Power factor meter no..... "									
	Description	Percent rated load (1)								
		10	20	30	90	100	110	120	etc.	
5	Applied voltage, volts.									
6	Line current, amperes									
7(2)	Line current, amperes									
8(3)	Percent power factor									
9	Gross weight on brake									
10	Rev. per min.									

(1) These are suggested percentages; the actual percentage in each trial must be determined exactly by dividing the output by the rated full load capacity.

(2) This item used only for 2 phase a.c. motors.

(3) This item not used for d.c. motors.

Testing of d.c. motors involves the use of voltmeters and ammeters to determine the input, and a brake or absorption dynamometer, such as is used for engine testing, to measure the output. In addition to the above, a power factor meter or wattmeter is used when testing a.c. motors.

Since electrical power is measured in watts and the brake dynamometer gives readings in horsepower, it is necessary to convert watts into horsepower by dividing by 746, as 746 watts equal 1 horsepower.

Efficiency of a d.c. motor is expressed by the equation:

$$\text{Eff.} = \frac{\text{Output}}{\text{Input}} = \frac{2 \times 3.1416 \times \text{rnw}}{33{,}000} \div \frac{\text{volts} \times \text{amperes}}{746}$$

in which values for the unknown terms in the equation are obtained from brake readings to correspond with simultaneous readings of volt and ammeters. However, computations are simplified when a series of readings is wanted by considering part of the numerator as constant, since its value does not change during any particular test. Thus, $\frac{2 \times 3.1416 \times \text{r}}{33{,}000}$ is known as the brake

constant, "r" being the length of the brake arm. The computation sheet gives this constant the designation Item 1. Therefore the simplified formula is

$$\text{Efficiency} = \frac{\text{Item 1} \times \text{n} \times \text{w} \times 746}{\text{volts} \times \text{amperes}}$$

Values for lines 5 to 10, inclusive, shown on the log sheet, must be obtained for each of the loadings called for on the right-hand side of the form. As explained in the footnote, these are only suggested loadings at which readings are to be taken; frequently some can be omitted and the curve still be plotted with sufficient accuracy. For any one loading, then, it is necessary to take simultaneous voltmeter, ammeter, brake and speed reading, and in the case of a.c. motors, power factor meter readings.

Computation of efficiencies for various types of motors can readily be effected by using the condensed formulas in the column headed "results from" on the computation-summary sheet.

In using the formulas given on the computation sheet, it should be understood that the values to be substituted for the various items which make up the formula must, for the efficiency at any per cent load, be those obtained during the test for the corresponding per cent load. For example, take the case of the single-phase a.c. motor, item 4. Here the efficiency is expressed as:

$$\text{Eff.} = \frac{\text{Line 10} \times \text{Item 1} \times \text{Item 2} \times 746}{\text{Line 5} \times \text{Line 6} \times \text{Line 8}}$$

For efficiency at 30 per cent load, the values to substitute for line 5 will be the applied voltage at 30 per cent load; for line 6, the amperes in the line current at 30 per cent load, and so on.

MOTOR EFFICIENCY TEST COMPUTATION—SUMMARY SHEET

Item	Description	Results from[2]	Per Cent Load	Rated Load
1	Brake constant $= \frac{2 \times 3.1416 \times r}{33{,}000} = \frac{2 \times 3.1416 \times \text{Line 4}}{33{,}000}$			
2	Net weight on brake "W"	Line 9 + Line 3[1]	10 20	100 110
3	Efficiency of d.c. motor	$\frac{\text{Line 10} \times \text{Item 1} \times \text{Item 2} \times 746}{\text{Line 5} \times \text{Line 6}}$		
4	Efficiency of single-phase a.c. motor	$\frac{\text{Line 10} \times \text{Item 1} \times \text{Item 2} \times 746}{\text{Line 5} \times \text{Line 6} \times \text{Line 8}}$		
5	Efficiency of 2-phase a.c. motor	$\frac{\text{Line 10} \times \text{Item 1} \times \text{Item 2} \times 746}{\text{Line 5} \times (\text{Line 6} + 7) \times \text{Line 8}}$		
6	Efficiency of 3-phase a.c. motor	$\frac{\text{Line 10} \times \text{Item 1} \times \text{Item 2} \times 746}{\text{Line 5} \times \sqrt{3} \times \text{Line 6} \times \text{Line 8}}$		

[1] Whether the tare of the brake (Item 3) is to be added or subtracted to obtain the net weight depends on the arrangement of the weighing mechanism.

[2] Meter readings used in this column are to be gross readings corrected for meter error.

Air Compressor Testing

In arranging forms on which to record compressor test data, it has been thought well to omit from consideration data pertaining to the measuring of the power input. These can readily be referred to in the case of steam engines, turbines and motors by turning to the data already given.

For our purposes we have assumed a reciprocating type of air compressor, and the air horsepower output is measured by the aid of indicator diagrams, just as in the case of the reciprocating steam engine.

As a means of comparing the performances of various compressors or those of the same compressor at different times the efficiency of compression will be found most satisfactory, as it can be applied to practically all types of compressors with slight modifications.

To show the derivation of the data in the forms, a brief explanation of the mathematical steps taken in the more important computations is given herewith.

To compute the net work in foot-pounds per minute at the air end of reciprocating or rotary machines, multiply the corrected volume of compressed air in cubic feet per minute (see next paragraph) discharged into the main delivery pipe, by the total pressure in pounds per square foot and by the hyperbolic logarithm of the ratio of the total pressure to the atmospheric pressure. All pressures must be converted to absolute pressures. Net air horsepower is then found by dividing the above product by 33,000.

The corrected volume of compressed air is found by reducing the volume of compressed air delivered per minute as measured, to atmospheric temperature, by multiplying it by the proportion:

$$\frac{460 + T_1}{460 + T_2}$$

in which T_1 = temperature of air supplied to machine.
T_2 = temperature of air in delivery main.

The capacity of the compressor is the volume in cubic feet of air measured as delivered per minute converted, for temperature and pressure, to free air. The pressure

AIR COMPRESSOR TEST LOG SHEET

Made by _____ on compressor No. _____ Date _____

Line No.	Description						Enter as Item
1	Description of Compressor Driven by Rating Dimensions Speed						
2	Time	8:00	8:30	10:00	Total	Average	
3	Barometric pressure of atmosphere, in. of mercury						
4	Temperature of air supplied to compressor, deg. F.						
5	Temperature of air in delivery main, deg. F.						
6	Pressure of air in delivery main, lb. per sq. in.						
7	Volume of compressed air delivered cu. ft.						
8	Area of air cylinder indicator diagram sq. in. divided by length of card. Scale of spring lb.						
9	Speed. Rev. per min.						

correction is made by multiplying the volume of air at delivery, corrected to atmospheric temperature, by the proportion $\frac{P_2}{P_1}$ in which P_1 is the atmospheric pressure and P_2 the total pressure in the delivery main, both pressures being absolute. The correction to atmospheric temperature is explained in the preceding paragraph.

Compressor capacity is frequently stated as the num-

AIR COMPRESSOR TEST, SUMMARY SHEET

Item	Description
1	Compressor No.....Tested by.....Date.....
2	To determine .....
3	Duration of test, hours and decimal parts (Test log, line 2)...
4	Type and size of driving machinery.....
5	Permanent data .....
5a	Dia. air cylinder piston.....
5b	Area air cylinder piston .....
5c	Dia. air cylinder piston rod.....
5d	Area air cylinder piston rod.....
5e	Net effective area piston (a) See note below[1].
5f	Stroke of air cylinder piston ft.....(L)
5g	Air compressor constant for 1 lb. m. e. p. and 1 working stroke per min. = $\frac{\text{Item 5e} \times \text{Item 5f}}{33{,}000}$
6	Rated capacity in cu. ft. of air per min.....
7a	Dia. (ft.) of delivery main.....
7b	Cross sectional area delivery main.....sq. ft.

Average Pressures and Temperatures

Item	Description	Results from	Data
8	Av. barometric pressure of atmosphere	Test log, line 3	..in. mercury
9	Av. temp. of air supplied to compressor	Test log, line 4	.....deg. F.
10	Av. temp. of air in delivery main	Test log, line 5	.....deg. F.
11	Av. gage press. of air in delivery main[2].....	Test log, line 6	lb. per .....sq. in.

Total and Hourly Quantities

Item	Description	Results from	Data
12	Total volume of compressed air delivered as measured...	Test log, line 7	.....cu. ft.
13	Total volume of compressed air delivered per hour as measured	Item 12 ÷ Item 3	.....cu. ft.
14	Total absolute pressure in delivery main, per sq. ft.....	(Item 11 + 14.7) × 144	.....lb.

Indicator Diagrams, Speed and Power

		Results from	Data
15	Mean effective pressure, air cylinders	Test log, line 8 × scale of spring	.....lb.
16	Revolutions per minute.....	Test log, line 9	.....r.p.m.
17	Indicated horsepower steam cylinder	From engine test	.....i. hp.
18	Gross indicated horsepower air cylinder[3].....	Item 15 × working strokes per min. × Item 5g	.....i. hp.
19	Corrected volume of compressed air per min., at atmospheric temperatures....	Item 23	.....cu. ft.
20	Ratio of total pressure (in delivery pipe) to atmospheric pressure [all pressures absolute].....	(Item 11 + 14.7) ÷ (Item 8 × 0.49)	.....
21	Net air horsepower.....	Item 19 × Item 14 × Hyperbolic log Item 20 ÷ 33,000	.....hp.

Capacity and Economy Results

Item	Description	Results from	Data
22	Compressed air delivered per min. as measured.....	Item 13 ÷ 60	.....cu. ft.
23	Compressed air per min. reduced to atmospheric temperature	Item 22 × (460 + Item 9) ÷ (460 + Item 10)	.....cu. ft.
24	Compressed air per min. reduced to atmospheric temperature and pressure (free air)	Item 23 × Item 20	.....cu. ft.
25	Dry steam consumed per net air hp.-hr.....	Steam per hour from test data ÷ Item 21	.....lb.
26	Heat units consumed per net air hp.-hr.....	Item 25 × total heat of steam less heat in water at exh. temp.	.....B.t.u.

Compression and Mechanical Efficiency

27	Efficiency of compression....	Item 21 × 100 ÷ Item 18	.....per cent
28	Mechanical efficiency of air compressing unit	Item 18 × 100 ÷ Item 17	.....per cent

Work Done Per Heat Unit

29	Net work per B.t.u.....	1,980,000 ÷ Item 26	.....ft.-lb.

Sample Diagrams

30	Sample indicator diagrams from each cylinder.....	.....	.....

[1] Net effective area for each side of piston equals area of piston when rod does not extend through cylinder head on the face in question, but is equal to the difference between the areas of the piston and the rod when the latter extends through the head.

[2] Additional data should be given in the case of compressors having more than one stage; this would include data with respect to temperatures and pressures in the different stages, the quantity of water used for cooling and temperatures of air and water entering and leaving the intercooler.

[3] In the case of rotary compressors this will be the brake horsepower consumed, measured by a dynamometer.

ber of cubic feet of compressed air delivered per minute at a given pressure (above atmospheric) reduced to atmospheric temperature.

The gross air horsepower output or measure of the work done by the air end of a reciprocating compressor is found in a manner identical with that of the reciprocating steam engine, by multiplying together the net area of the air piston in square inches, the mean effective air pressure in pounds per square inch (as determined from indicator diagram) the length of stroke in feet and the number of working strokes per minute, and dividing this product by 33,000.

Efficiency of compression in a reciprocating machine is determined by first computing the net work at the air end, as described in a previous paragraph, and dividing this result by the gross air horsepower.

The mechanical efficiency of a reciprocating air compressing unit is determined by dividing the gross air horsepower at the air end by the indicated horsepower at the steam end, or, in case the compressor is not driven in this manner, by the horsepower of the driving medium, determined by a dynamometer or computed from test data.

BLUEPRINTS are always getting dirty, wet, greasy or torn while being handled by workmen using them.

An inventive genius has designed a very practical blueprint protector of simple construction and low cost.

A sheet of transparent sheeting—the same material used for lights in auto curtains—is cut to desired size. A piece of light-weight leather substitute is then cut about a half inch larger all around than the piece of sheeting. This extra half inch allows for a lap-over on all but the top side of the protector. A sewing machine stitches the lap down to the sheeting, forming a large flat pocket, open at the top for the insertion of the blueprints.

Both the transparent front and the coated fabric back are water-proof and grease-proof. Dirt or grease may easily be wiped or washed off either without injury.

Planning Operating Log Sheets

METHOD OUTLINED; FORMS DEVELOPED; ITEMS CLASSIFIED AS TO IMPORTANCE

WHEREVER a commodity changes hands or is handled mechanically, wherever a physical, chemical or energy change takes place, there is a chance for a loss and each transaction or change should be studied in detail to determine what items, if any, affecting the change should be kept for comparison. If any variation likely to occur affects the overall cost an appreciable amount or endangers the safety of the plant, that item should by all means be made a part of the daily record.

In planning a log sheet which will enable the engineer to study operating conditions with the object of reducing costs, two angles of attack may be employed, and the overlapping data eliminated. First list all equipment of the plant, study the work of each equipment and make note of all variable conditions which affect this operation. From this list determine what instruments are needed and what data can be used to advantage for comparison at various times.

TABLE OF HEAT LOSSES IN STEAM PLANT

Heat losses between furnace and power shaft		96.6%
Boiler		35%
Ashpit	3	
Radiation	3	
Gases	29	
Steam main to engine		9
Radiation	3	
B. F. pumps	3	
Cond. pumps	2	
Hot well pumps	1	
Engine		50
Radiation	1	
Friction	1	
Exhaust steam	48	
Generator		0.4
Switchboard		0.3
Transformer		0.3
Motor		0.6
Shafting		1.0
Friction	0.9	
Belting	0.1	

Next trace the fuel, water, supplies, etc., that is, all items which go to make up variable charges from the time of purchase or entrance into the plant, through the various changes to the ultimate product, use or rejection from the plant. All along the line, notes should be taken of conditions which affect results. Notes should be made of the instruments needed and data which can be used to advantage for comparison.

Having gone thus far with the problem, it will be found advisable to eliminate many of the items from the daily log which are of interest but entail more clerical work than is at the disposal of the plant force and variations during ordinary operation which are not sufficient to change appreciably the overall results. Such conditions can be made the subject of special tests at sufficiently frequent intervals to maintain the plant in first rate condition.

To get a line on what part of the plant needs most attention from the standpoint of keeping records, it is well to make a general analysis of the heat losses that occur from the coal pile to the driven machine. A study of this list of losses points directly to the machine or equipment where likelihood of greatest saving is possible and at these places the most complete records should be kept.

Equipment	Kind	Operating Data Arranged in the Order of their Importance		
Coal and Ash	Bucket	1.Power Consumed 2.Labor Employed	3.Coal Handled 4.Ash Handled	5.Time Started 6.Time Stopped
3 Boilers	Water Tube	1.Pressure 2.Superheat 3.Safety Valve opened 4.Feed Water per hr. 5.Lb.steam each Boiler pr.Hr.	6.Feed Water Temp. 7.Hrs.in operation 8.Time blown down-account 9.Tubes dusted 10.Feed water flow	11.Water level 12.Steam flow 13.Boiler water tested
3 Furnaces	Chain Grate	1.Coal per hr. 2.CO2 3.Gas Temp. 4.Furnace & Diff. Draft	5.Kind coal 6.Smoke Temp. 7.Ash made 8.Depth of fuel bed	9.Stoker speed 10.Air temp. 11.Barometric press.
2 Stoker Engines	Upright	1.Time start 2.Time stop 3.Speed	4.Steam press. at throttle 5. Ihp.	
1 Feed Water Heater	Open	1.Total water heated 2.Temp. inlet 3.Temp. outlet	4.Exh. steam press. 5.Steam temp. 6.Water flow from	
2 Boiler Feed Pumps	Duplex Plunger	1.Start 2.Stop	3.Strokes 4.Water press.	
2 Vacuum Pumps	Simplex	1.Start 2.Stop 3.Strokes	4.Vacuum 5.Outdoor Temp. 6.Return Water Temp.	7.Amount return water
1 Fire Pump	Underwriters	1.Timetested	2.Press.Record	
2 Compressors	Ammonia	1.Start 2.Stop	3.Suction Press. 4.Head Press.	5.Temp.Suction 6.Temp.Discharge
2 Motors	D.C. drive Ammonia Comp.	1.Start 2.Stop	3.Kw. Hr	4.Half hourly Amps.
3 Engines	Non Releasing Corliss	1.Start 2.Stop	3.Steam press. 4.Exh. press.	5.Indicated hp.
3 Generators	D. C.	1.Start 2.Stop	3.Kw.Hr. Day 4.Volts ½ hr.	5.Amps. ½ hr.
3 balancing sets	Rotating	1.Start 2.Stop	3.Volts + side 4.Volts - side	5.Amp. + side 6.Amp. - side
1 Switchboard	3 wire	1.Departments on 2.Departments off	3.Kw.hr each ½ hr.	4.Total
2 Sewage Ejectors	Automatic Compressor Air	1.Operation In 2.Operation Out	3.Number of Dumps	4.Sewage ejected
2 Compressors	Air Automatic Starter	1.Start 2.Stop	3.Number of Starts 4.Air Press.	5.Temp.Cooling Water
2 Motors	D. C. drive air compressors	1.Start 2.Stop	3.Kw.hr. per day	4.hr. Kw. hr.
1 Sump Pump	Cent. Turbo drive	1.Start 2.Stop		
2 Filters	Press.	1.Used	2.Not Used	3.Water Filtered
2 House Pumps	Triplex Motor drive	1.Start 2.Stop	3.Press.½ hr. 4.Revolutions	5.Water Pumped
2 Motors	D. C. Drive House Pump	1.Start	2.Stop	3.Kw.hr.day or ½ hr.
Heating System	Exhaust Steam with Live Steam Aux.	1.Back Press. 2.Return Press. 3.Live steam on. 4.Outside Temp.	5.Inside Temp. 6.Wind direction & velocity 7.Humidity outside	8.Humidity inside 9.Barometric reading
10 Elevators	Electric	1.Running time 2.Kw.hr.per day 3.No. of trips	4.Passengers up ½ hr.	5.Passengers down ½ hr. 6.Time per trip
1 Elevator	Hydraulic	1.Running Time	2.No. of Trips	
10 Fans	Motor drive	1.Start 2.Stop	3.Kw. hr.	4.Air press.

FIG. 1. TABULATION OF POWER PLANT MACHINERY IN MODERN OFFICE BUILDING AND ITEMS FOR RECORD IN THE ORDER OF THEIR IMPORTANCE

Having decided upon what data should be kept, the next step is to arrange the items in a logical, easily kept form to be filled in as the work proceeds during the day. In some plants, the keeping of several record forms is advisable; in others, one form can be designed to suit the needs. For the engine in charge of a plant, the

operating record is the most important, as it enables him by comparison to determine what condition under his control to maintain in order to secure the highest efficiency and lowest unit cost under the existing load and weather conditions outside of his control.

In a daily log sheet will naturally be included many items which have to do with costs; others indicate efficiencies or needs for improvement in equipment; but in planning this log sheet, it is necessary to keep in mind that the main object is to find the operating conditions which will give the best results.

To illustrate the methods outlined above in a specific case, a modern office building of medium size has been selected. This plant contains a sufficient variety of equipment to make the problem applicable to most steam power plants by simply substituting detailed descriptions, eliminating items not applicable to the particular plant and adding items for such equipment as may not be contained in this plant.

In the accompanying tabulation headed "Plant Equipment" is given the name of the equipment, the kind and the items which should be made part of the operating record. Taking up this equipment item by item, the relative importance of the record data will be pointed out.

Conveying Equipment

We find in this plant that the coal and ash conveying equipment is of the bucket type, and that the driving power is a motor. The sole object of installing such equipment is to cut down the cost of handling coal and ash. If the equipment fails to perform this service more cheaply than it could be done by manual labor, it will readily be recognized that the equipment is a failure. It is, therefore, of first importance to know the amount of power consumed and the labor employed to operate the machinery. From these two items we are able to determine the cost of operating the equipment per day when from other records we have obtained the cost of power and labor. Now, to get this cost down to a unit basis, it is necessary for us to know the amount in pounds or tons of coal and ash handled. Knowing these, we can readily calculate the cost per ton of handling coal or ashes. These four items, therefore, are of primary importance: Namely, the amount of power consumed by the motor, which can be measured by wattmeter and which is read once a day; labor to operate the equipment should be noted by the man in charge at the time the conveyor is in operation; the amount of coal will be identical to that received at the plant during the day of which a record must be kept; and the amount of ash should be measured or weighed as it leaves the plant.

Time	7A.M.8	9	10	11	12	1P.M.	Totals or Averages
Steam Press.							
Steam Temp.							
Steam Quality							
Exhaust Steam press.							
Air Temp. Outside							
Air Temp. Inside							
Air Humidity Outside							
Air Humidity Inside							
Barometric Press.							
Wind Direction							
Wind Velocity							
Water Meter - City							
High Press. Steam Condensate-lb.							

FIG. 3. LOG FOR GENERAL DATA

In an adequate record, therefore, these four items covering the coal and ash conveying equipment are necessary, and these readings need be recorded but once a day. If, however, further information is desired regarding the conveying equipment, it would be well to include the time for starting and the time of stopping. These items will give the engineer a check on his program of operation, which should be so arranged as to give the most even load on the plant.

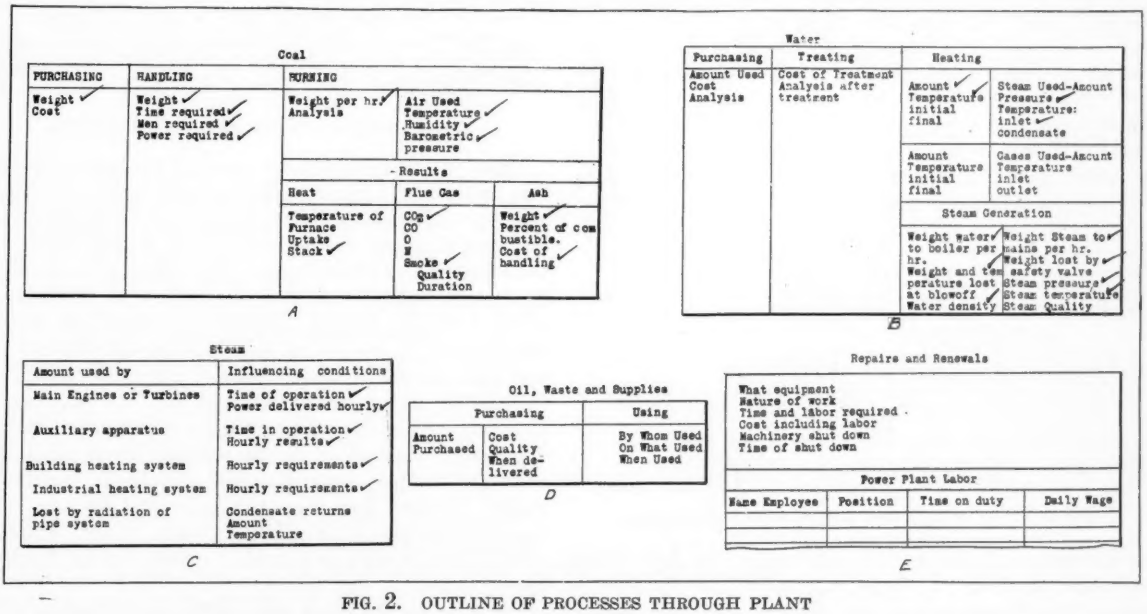


FIG. 2. OUTLINE OF PROCESSES THROUGH PLANT

Boilers and Furnaces

In the tabulation we have listed three water tube boilers, which are equipped with three chain grate stokers. The boiler and furnace may be considered as a unit, but they are here taken up separately in order that detailed analysis of the work done by each may be considered. First of all, the fireman is required to maintain an even pressure, so that a record of this is of first im-

portance, and as the pressure is likely to vary considerably, readings should be taken at least every hour. In many plants, a recording steam pressure gage will be used to show these variations, and from this the average of the day may be calculated and the average recorded on the daily log sheet. Along with this item is the amount of superheat which, of course, is calculated by subtracting the temperature of saturated steam of the given pressure from that of the steam as delivered. If desirable, the record of steam temperature only may be made and the calculation of superheat may be made later when the final calculation of the log sheet is made.

The next item of importance has to do with the safety of the boiler and this should be made a matter of record;

Oil, Waste and Supplies Used						Repairs and Renewals				Labor			
												Time	
Oil Kind	Gal.	Cost	Waste Kind	Lb.	Cost	Machine	Parts renewed or repaired	Employe	Time	Cost	Employe	Position	From	To	Hours
No. 1			No. 1												
No. 2			No. 2												
No. 3															
No. 4															
No. 5															
Total															
Supplies Name		Amount		Unit Cost	Total Cost										

FIG. 4. LOG SHEETS FOR OIL, WASTE AND SUPPLIES, REPAIRS AND RENEWALS, AND LABOR

namely, the time of the safety valve opening. In many plants, it is customary to test the safety valve at least once a day, either by bringing the steam pressure up to the popping off pressure or by opening the valve by means of the lever. This point should not be overlooked, for in cases of accident considerable controversy always hinges around the reliability of the safety valve.

The item of next importance having to do with the boilers is the weight of feed water delivered to the battery per hour. This item may be read from a feed water meter and would give a close account of what the plant is doing at various times throughout the day. In conjunction with the amount of feed water being fed, it is convenient to know the amount of steam being delivered from each boiler during each hour of the day. Close attention to these two items will show how the load is being distributed among the boilers, also how nearly each boiler is working to its point of maximum efficiency. For taking these readings a flow meter is used, the most convenient type being one which will give a graphic record of the amount of steam being delivered and integrating the amount of steam which has been delivered over a given period.

Time of day	7A.M.			8			9			10			11			12			1P.M.			2			Total or Average			
Boiler No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Coal burned																												Kind of Coal
Feed Water																												
CO_2																												Coal Burned per sq. ft. Grate surface per hr.
Gas Temp.																												
Safety Valve Opened																												
Lb. Steam Meter																												Pounds steam per pound coal burned
Draft Furnace																												
Draft Differential																												
Feed Water Temp.																												
Smoke Record																												
Ashes Made																												
In Operation																												
Blowdown - gages																												
Tubes Quited																												
Depth fuel																												
Stoker Speed																												
Water level																												
Boiler Water tested																												

FIG. 5. LOG SHEET FOR BOILERS AND FURNACES

Much depends upon the temperature of the water fed to the boiler, both from the standpoint of safety and efficiency. As a rough estimate, for each 11 deg. the feed water is raised in temperature by the waste heat of a plant, the amount of fuel required to generate the steam is reduced 1 per cent. It is advisable therefore, to have in the log sheet space for recording the temperature of the feed water at intervals ranging from ½ to 2 hr., depending upon the convenience with which the readings can be taken.

The program of operation of the boilers should not be omitted from the log sheet, as in many cases the plant can be run much more economically by simply changing the program of operation, so that the load upon the boilers is kept near the maximum point of efficiency. Comparison between the hours in operation and the steam generated by each boiler per hour will readily show whether or not the boilers which are generating steam are running above or below their normal rate of capacity. This item then will give the engineer data from which he can work out his schedule of operation, and see that his directions are being carried out.

The time of blowing down a boiler depends pretty largely upon the load curve of the plant and the quality of the water being used in the boiler. The steaming qualities of the boiler are improved by blowing down, also the likelihood of priming is reduced, so it is well to have a record of this in our daily sheet. Not only should the time of blowing down be recorded, but also the amount, that is the number of gages the water level is reduced. If the operator is required to make a record of this amount, there is less likelihood of his going off and leaving the boiler blowoff valve open than when no record is kept.

	7A.M.	8	9	10	11	12	1	2	3	4	Average or Total	
Temp. Inlet												Deg. F.
Temp. Outlet												Deg. F.
Exh. St. Press.												lb. or oz.
Steam Temp.												Deg. F.
Metor Reading												Lb.

FIG. 6. LOG SHEET FOR FEEDWATER HEATER

Soot will collect on the gas side of the heating surface very rapidly and to maintain the highest rate of evaporation the tubes should be dusted quite frequently, depending of course on the kind of coal being burned and the efficiency of the furnace. The effect of dusting the tubes can readily be seen when a flue gas thermometer of the recording type is installed. To make sure that the instructions in regard to soot blowing are carried out, this item should be made a part of the daily record.

Among the items which will aid the engineer in maintaining highest efficiency when all other points have been taken care of as far as possible are a continuous record of the feed water flow into each boiler, continuous record of steam flow from the boiler and an item showing the quality of the boiler water tested which in some plants is used as a guide to when boilers should be blown down.

Taking up the items which affect the operation of the furnace, that which should receive first consideration is the amount of coal burned. This should rightfully be recorded hourly with a summation at the end of the day. Such frequent readings may not be convenient, as all plants are not equipped with weighing apparatus, so that in this case the total amount for the day would be recorded on the log sheet.

The item of next importance is the amount of CO_2 in the flue gases. This indication is the most convenient and accurate which is available for determining the efficiency of combustion, and if possible the reading should

be taken by a recording type of instrument, but if this is not practicable, samples could be gathered during the day and the average be determined by means of a hand sampling apparatus.

The next item of importance is the item of flue gas temperature, which is an indication of the heat absorbing ability of the boiler. With scale accumulation on the inside of the heating surface and soot on the outside, there is a gradual increase in the flue gas temperature between the times of cleaning the inside of the boiler and the soot blowing on the gas side of the heating surface. By noting the gas temperature, therefore, the engineer can readily determine how frequently the boiler should be cleaned or dusted.

In case the plant is not equipped with CO_2 recording machine the most convenient guide for the fireman is a set of draft gages indicating the draft in the furnace, and the differential draft between furnace and the stack. While the information gained by these gages is of more direct use to the fireman than to the engineer in charge, it is well to make these readings a part of the daily records, being noted on the log sheet at frequent intervals.

The operation of a furnace is so dependent upon the kind of coal being burned that this item should be included as part of the daily record. For example, coal of different sizes requires different draft pressures so that the engineer must be able to give instructions to

	Start	Stop	Hrs. Run.	No. of strokes	Kw. hr. Used	Pressure, lb., or Vacuum, in. mercury at 7	8	9	10	11	12	1	2	3	Total Water Pumped
Boiler Feed No. 1															
Boiler Feed No. 2															
Vacuum No. 1															
Vacuum No. 2															
Fire, tested															
Sump															
Water No. 1															
Water No. 2															

FIG. 7. LOG SHEET FOR PUMPS

the fireman as to the amount of draft to be maintained in the furnace for different kinds of coal; also, with coal having different percentages of volatile matter or ash of different fusing temperatures, the draft and rate of combustion must be varied accordingly.

Many of the American cities have smoke prohibition ordinances and as a matter of protection against unjust prosecution, smoke recording and indicating devices have their place in the power plant. If possible, a record should be kept of the duration and the quality of smoke, which evidence would have considerable weight in court.

The pounds of ash made during the day should be checked against the amount of coal burned, and the amount of ash shown by the coal analysis. By means of these items, we are able to tell the efficiency of the grate for the kind of coal being burned without necessity of making an analysis of the ash to find out how much combustible there may be in it. This, however, should be done occasionally in order to see that the method of checking is sufficiently accurate.

In this type of stoker, the method of regulating the rate of combustion is by varying either the depth of the fuel bed or the speed of the stoker. Therefore, in a study of the proper furnace conditions for different kinds of coal and the draft conditions, it is well to make note of the depth of the fuel bed and stoker speed at regular intervals during the day. It is also an advantage to know the temperature of the air entering the furnace, as this must all be raised to the temperature of the flue gases and the losses due to this cause are in proportion to the difference in temperature between that of the air at inlet and the flue gases. A study of the physical arrangement of the plant will sometimes suggest a means of utilizing the waste heat from other parts of the plant for increasing the temperature of the air entering the furnace which would prove to be an economical arrangement.

When depending upon natural draft for furnishing air to the furnaces, the operation of the furnace is affected greatly by the barometric pressure of the at-

	Start	Stop	Hours Run	Kw. hr. Used	Time	7	8	9	10	11	12	6	Ave.
Ammonia No. 1					Amps.								
Ammonia No. 2					Amps.								
					Suc. Press.								
					Head								
					Temp. Suc.								
					Temp. Disc.								

	Start	No. of Auto. Starts	Stop	Hours Run	Kw. hr. Used									
Air No. 1						Cooling Water Temp								
Air No. 2						Cooling Water Temp								
						Air press.								
						Meter No. 1								
						Meter No. 2								

FIG. 8. LOG SHEET FOR COMPRESSORS

mosphere. In order, therefore, that the proper combustion may be secured in the furnace, the engineer will do well to make a study of the barometric pressure and the draft for different kinds of coal, various load conditions and rates of combustion. If the barometric pressure is recorded on the daily log sheet, together with the other items mentioned above, necessary for making these comparisons, he can give more intelligent instruction to his fireman as to the proper draft to carry under the existing conditions.

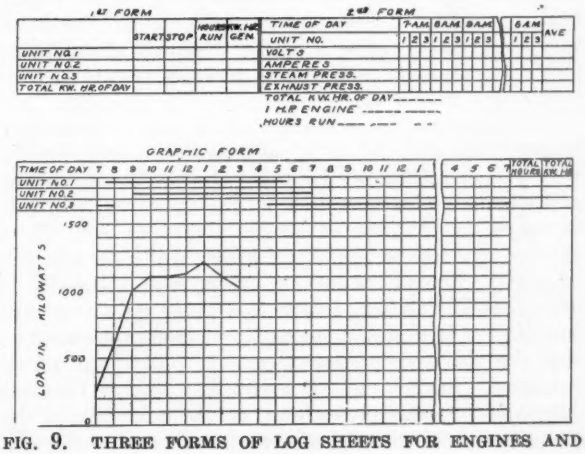


FIG. 9. THREE FORMS OF LOG SHEETS FOR ENGINES AND GENERATORS

In this plant, the stokers are driven by two upright steam engines, either one of which is of sufficient capacity to operate all three of the furnaces. The speed of these engines is under the automatic control of the steam pressure, so that the principal items to be recorded on the log sheet are the time of starting and stopping each engine. This gives a check on the firemen to see that they are following out the instruction of the engineer as to which engine is to be used.

The next item of importance is that of the speed of the engine, which taken together with the pressure of

steam at the throttle will give a check on the operation of the automatic mechanism which controls the speed of the furnace. This investigation, however, as well as the indicated horsepower of the engine, may be made the subject of a special test which should be made at regular intervals, and need not be recorded on the daily log sheet. It is desirable to know how much power is being used in the operation of the stokers and also that the speed is being maintained for the load which is being carried, but an investigation can be made as mentioned above.

Feed Water Heater and Pumps

The boiler feed water is heated in an open type of feed water heater. Here the principal items which should be recorded are the total amount of water heated,

	Start	Stop		7	8	9	10	11	12	Average
Balancing Set No. 1			Volts +							
			Volts −							
			Amp +							
			Amp −							
Balancing Set No. 2			Volts +							
			Volts −							
			Amp +							
			Amp −							

Switchboard	Circuit Closed	Circuit Opened		7	8	9	10	11	12	Total
Circuit No. 1			Kilowatts							
Circuit No. 2										
Circuit No. 3										
Circuit No. 4										
Circuit No. 5										
Circuit No. 6										
Circuit No. 7										
Circuit No. 8										

FIG. 10. LOG SHEET FOR BALANCING SETS AND SWITCHBOARD

which should be identical to that fed to the boilers. Next comes the temperature of the water as it enters the heater and as it leaves it, which gives a check on the efficiency of the heater. The pressure of the exhaust steam as it enters the heater is also of importance, as from this item we are able to tell whether or not the back pressure valve is operating correctly, and by reference to the steam tables we can find the steam temperature or this may be read direct from a thermometer placed in the inlet.

In the plant are two duplex plunger type boiler feed pumps. The items of principal importance having to do with the operation of these are the times of starting and stopping, also as a check on the operation it is well to record the number of strokes made per day. This checked against the feed water heater will show whether or not the pumps are leaking excessively or the slip is unreasonable. Where boiler feed-water regulators are installed, it is necessary to employ a pump governor so that the discharge pressure from the pump will not be excessive. In such cases, it is well to record at frequent intervals the water pressure in the discharge pipe of the pump as a check against the operation of the pump governor.

In the heating system two vacuum pumps of the simplex type are installed, and the principal items to be recorded here are as above, the times of starting and stopping and the number of strokes made during the day. It is also important to know the vacuum maintained in the suction line, as upon this to a great extent depends the efficiency of the heating system. These last two items could be checked against the outdoor temperature and the temperature of the return water, both of which can be read at frequent intervals from thermometers placed in the proper location.

As considerable controversy exists as to the proper division of costs between the electric and heating loads of a plant, it is of value to know the amount of return water from the heating system. This, of course, may be estimated by the number of strokes made by the pump, but the better method is to measure the return water by means of a meter. By this method we have a means of checking the leakage and slip of the vacuum pumps.

Fire Pumps

As a matter of safety, it is necessary to keep the fire pump in perfect working order, and maintain the pressure of the sprinkling system up to the proper point at all times. It is important, therefore, that in the daily log sheet we keep a record of the time when the pump is tested to see that it will work up to the full capacity when pressure is reduced on the sprinkling water system. As a matter of precaution, it is well to have on this sprinkling system a recording pressure gage which will keep a continuous record of the pressure on the system. With this record at hand, any controversy with the insurance company as to the reliability of the pump can readily be settled.

Ammonia Compressors

The two ammonia compressors installed in this plant are used for cooling the drinking water; so in order to keep a line on the operation of the system, it is necessary to keep a record of the time of starting and stopping the compressors, also the suction and head pressures, which, together with the temperature of the suction and discharge gases, will give a good line on the operation of the compressors. As the compressors are

Coal and Ash Conveyor	Start	Stop	Hours run	Kw. hr. Used	Labor	Coal handled	T. Ash handled T.
Stoker Engine No. 1				Speed r.p.m.	Steam press. lb.	I.hp.	
Stoker Engine No. 2							
Sewage Ejector No. 1				No. of Pumps	Sewage Ejected	gal.	
Sewage Ejector No. 2							
Filter No. 1				Water Filtered	Gal.		
Filter No. 2							
				Power Used Kw. hr.	Air Press. at 9 a.m. in. water	3 p.m. in. water	
Ventilating Fan No. 1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

FIG. 11. LOG SHEET FOR AUXILIARIES

driven by motors, direct connected to them, the unit may be taken as a whole; but we have divided it in the tabulation in order that the items may be more clearly pointed out, so in the daily log sheet the time of starting and stopping the motors will be the same as that for the compressors, therefore no separate items are necessary. The power consumed per day, however, is of considerable importance and should be read once a day from the meters on each circuit to the motors. To note how the load is distributed throughout the day, hourly readings should be taken of the amperes in the circuits to the motors.

Engines and Generators

The principal engines of the plant are of the non-releasing Corliss valve type. With them the items of principal importance from an operating standpoint are the time of starting and stopping each engine, also the steam and exhaust pressures, which are probably recorded in some other part of the plant; although, for

best operation, gages should be placed close to the engines for the observation of the operator. In the operation of the engines, it would not be at all out of place to take a set of indicator diagrams at least once a day from each engine, and from this calculate the indicated horsepower. This would, of course, entail extra work; but an examination of the card will indicate almost immediately any changes in the adjustment of the valve or other conditions which might affect the efficient working of the engine.

In regard to the generators which are directly connected to the engines, it is not necessary to make a separate record of the time of starting and stopping; but it is important that a record be kept of the power generated during the day by each generator. It is also well to record at least every half hour the voltage and current delivered by each machine, and in the case of alternating current generators, the power factor or kilowatts delivered should be made a part of the daily record with readings taken not more than one-half hour apart. The most convenient instrument for doing this work is one of the graphic recording type which would not fail to show all the variations during the day.

Electrical Data

The plant in question having the three-wire system of electric current distribution two balancing sets of the rotating type are installed, so that the time of starting

	6 a.m.	9	12	3	6 p.m.	9	12	3	Average or Total
Back Pressure									lb.
Return Pressure									"
Live steam On									hr.
Outside Temp.									Deg. F.
Inside Temp.									"
Wind direction									
Wind Velocity									mi. per hr.

FIG. 12. LOG SHEET FOR HEATING SYSTEM

and stopping should be recorded on the log sheet, also the voltages and amperes on the positive and negative sides. To be of great value the latter readings should be taken at least every half hour or as stated above the recording type of instrument is much preferred.

Practically all the electrical instruments in the plant are mounted on the switchboard, and as those already mentioned in connection with the generators and the balancing sets are among them, they will not be considered further. It is necessary, however, that a check be kept on the amount of power being delivered to the switchboard, which is the sum of that generated by the generating units. It is also important that a record be kept as to when the power is turned on or off from the different departments, and for each circuit a record of the power used should be kept. This may be read from a wattmeter every half hour so as to give a load curve for the department, or if the load is of a constant nature, it may be totaled for the day from the readings of the watthour meter.

Sewage Disposal

In the plant are two sewage ejectors automatically operated by compressed air. It is important to know when these ejectors are in operation, and this should be made a matter of record on the daily log sheet. For comparative purposes also of sewage ejected and the number of occupants in the building it is desirable to know the number of dumps, also the amount of sewage ejected during the day.

For operating the ejectors, two air compressors are employed, which are equipped with automatic starters to maintain the proper air pressure at delivery. The time of putting these in operation as well as taking them out of service should be part of the daily record. It is also important to know the number of starts which each machine makes, as considerably more power is used in starting the compressor than when it is kept in operation, so this information can be used to advantage in giving

	Running Time From	To	Power Used	No. of trips	Average Time one Trip	Passengers Carried per half hr. up and down 7:30 Up	Down	8:30 Up	Down	9:30 Up	Down	Total Up	Down
Electric No. 1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
Hydraulic No. 1													
					Total								

FIG. 13. LOG SHEET FOR ELEVATORS

directions as to the program of operation. It is also important to know that the air compressor is kept up to the standard, therefore this should be made part of the record. As the efficiency of the compressor depends somewhat on the temperature of the cooling water in the jacket of the compressor cylinder, this item will be of use to the engineer in maintaining the desirable conditions.

The motors for driving the compressor are directly connected so that the time of starting and stopping these will be taken care of in connection with the compressors

	6	9	12	3	6	9	12	3	Average
Steam Press.									
Exh. Steam Press.									
Air Temp. Outside									
Percent CO_2									
Flue Gas Temp.									
Feed Water Temp.									
Safety Valve Opened									

City Water Used
Reading Today
Reading Yesterday
Difference Gal.
Coal Burned
Water Evaporated
Lb. Water per lb. coal

	Start	Stop	Hours Run	Wattmeter Readings Today	Yesterday	Difference
Generating Unit No. 1						
2						
3						

Total Kw. hr. delivered
Lb. Coal per Kw. hr.

	Oil Used		
Kw. hr. or steam used	Kind	Gal.	Cost

		Supplies	
		Name	Cost

		Repairs	
		Machine	Cost

Boiler	No. 1		
Boiler	No. 2		
Boiler	No. 3		
Boiler Feed Pump	No. 1		
Boiler Feed Pump	No. 2		
Vacuum Pump	No. 1		
Vacuum Pump	No. 2		
Fire Pump tested			
House Pump	No. 1		
House Pump	No. 2		
Sump Pump			
Amco. Comp.	No. 1		
Amco. Comp.	No. 2		
Air Comp.	No. 1		
Air Comp.	No. 2		
Coal and Ash Conveyor			
Live Steam on Htg. System			
Ventilating Fans	1 to 10		
Elevators	1 to 10		

Labor		Time			Remarks
Position	Employe	From	To	Hrs.	

FIG. 14. COMPLETE FORM OF LOG SHEET DESIGNED TO RECORD ONLY ABSOLUTELY ESSENTIAL DATA

on the log sheet. It is important to know the amount of power used during the day for compressing the air; also, in order that the distribution of the air during the day may be known, hourly readings of the kilowatt hour meter on each machine should be taken.

For daily operating record purposes, about the only item needed or necessary in regard to the centrifugal turbine-driven pump are the times of starting and stopping. This pump is used only in case the automatic ejectors are not able to take care of the sewage as rapidly as it accumulates, and as the load is practically

constant during the time of operation the power consumed may be made a subject for test at regular intervals, so that the power or steam required may be summed up at the end of the day or month.

Filters and House Pumps

Two filters of the pressure type are used for purifying the drinking water, and as these require frequent cleaning, it is desirable to know when they are in use and when not. Also, as a guide in directing the plant, it is desirable to know the amount of water filtered by each filter during the day, which may be read directly from the water meters.

The house pumps are of the triplex motor driven type,

First Watch

Time of Day	7			8			9			10			11			12			1			2			Total or Av			
Boiler No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Coal Burned																												Kind of Coal
Feedwater Delivered																												Pounds Coal Burned per
CO_2 in Flue Gas																												Sq. Ft. of Grate per hr.
Flue Gas Temp.																												Pounds Steam Generated
Safety Valve Opened																												
Rate of Steaming																												Per Pound of Coal
Draft in Furnace																												
Draft Differential																												
Feed Water Temp.																												
Smoke Record																												
Ash made																												

Second Watch

Time of Day	3			4			5			6			7			8			9			10			Total or Av			
Boiler No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Coal Burned																												Kind of Coal
Feedwater Delivered																												Pounds Coal Burned per
CO_2 in Flue Gas																												Sq. Ft. of Grate per hr.
Flue Gas Temp.																												Pounds Steam Generated
Safety Valve Opened																												
Rate of Steaming																												Per Pound of Coal
Draft in Furnace																												
Draft Differential																												
Feed Water Temp.																												
Smoke Record																												
Ash made																												

Third Watch

Time of Day	11			12			1			2			3			4			5			6			Total or Av			
Boiler No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Coal Burned																												Kind of Coal
Feedwater Delivered																												Pounds Coal Burned per
CO_2 in Flue Gas																												Sq. Ft. of Grate per hr.
Flue Gas Temp.																												Pounds Steam Generated
Safety Valve Opened																												
Rate of Steaming																												Per Pound of Coal
Draft in Furnace																												
Draft Differential																												
Feed Water Temp.																												
Smoke Record																												
Ash made																												

Feed Water Heater

Time of Day	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	Ave. or Total	
Temp. Inlet																										Deg. F.
Temp. Outlet																										Deg. F.
Exh. Steam Press.																										Lb. or Oz.
Exh. Steam Temp.																										Deg. F.
Meter Readings																										Lb.

Pumps

	Start	Stop	Hrs. Run.	No. of strokes	Kw. hr. Used	Pressure lb. or Vacuum, in. mercury at. 7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	Total Water Pumped	City Water Used during Day
Boiler Feed No. 1																															
Boiler Feed No. 2																															
Vacuum No. 1																															
Vacuum No. 2																															
Fire, tested																															
Sump																															
House No. 1																															
House No. 2																															

Auxiliaries

	Start	Stop	Hours run																												Remarks
Coal and Ash Conveyor				Kw. hr. Used							Labor			Coal handled							T. Ash handled				T.							
Stoker Engine No. 1				Speed				r.p.m.			Steam press.				lb.						I. hr.											
Stoker Engine No. 2																															
Sewage Ejector No. 1				No. of Pumps							Sewage Ejected							gal.													
Sewage Ejector No. 2																															
Filter No. 1				Water Filtered							Gal.																				
Filter No. 2																															

Heating System

	6 A.M.	9	12	3	6 P.M.	9	12	3	Average or Total	
Back Pressure										lb.
Return Pressure										
Live steam On										hr.
Outside Temp.										Deg. F.
Inside Temp.										
Wind direction										
Wind Velocity										

FIG. 15. COMPLETE LOG FORM FOR BOILER ROOM PERMITTING COMPARISON BETWEEN WATCHES AND OTHER DETAILS OF OPERATION

and the time of starting and stopping these should be made a part of the daily record. It is important that the pressure in the system of the supply tank be kept up to standard, so that this item should appear in the records with readings taken at half hourly intervals, or better still a recording pressure gage should be provided.

time of starting and stopping. It is most important, however, that the power consumed by the motors during the day should be included in the record. Better still, half hourly records would give the engineer a better idea as to the amount of water being consumed during the different times of the day.

	First Watch									Second Watch									Third Watch								General Average
	7	8	9	10	11	12	1	2	Average	3	4	5	6	7	8	9	10	Average	11	12	1	2	3	4	5	6	Average	
Steam Press.																												
Exh. Press.																												
Air Temp. Outside																												
Air Temp. Inside																												
Barometric Press.																												

Engine Room

First Watch

Time of day	7			8			9			10			11			12			1			2			Average			Kw.hr. of Shift	I.H.P.
Engine No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		
Volts																												Eng. No. 1	
Amperes																												Eng. No. 2	
Steam Press.																												Eng. No. 3	
Exh. Press.																												Total	

Second Watch

Time of day	3			4			5			6			7			8			9			10			Average			Kw.hr. of Shift	I.H.P.
Engine No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		
Volts																												Eng. No. 1	
Amperes																												Eng. No. 2	
Steam Press.																												Eng. No. 3	
Exh. Press.																												Total	

Third Watch

Time of day	11			12			1			2			3			4			5			6			Average			Kw.hr. of Shift	I.H.P.
Engine No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		
Volts																												Eng. No. 1	
Amperes																												Eng. No. 2	
Steam Press.																												Eng. No. 3	
Exh. Press.																												Total	

Electrical

	Start	Stop	Hrs. Run	Time of Day	First Watch 7	8	9	10	11	12	1	2	Second Watch 3	4	5	6	7	8	9	10	Third Watch 11	12	1	2	3	4	5	6	Average
Balancer Set No. 1				Volts																									
				Volts -																									
				Amp.																									
				Amp. -																									
Balancer Set No. 2				Volts																									
				Volts -																									
				Amp.																									
				Amp. -																									

Switchboard	Time Closed	Circuit Opened	Time of Day	First Watch 7	8	9	10	11	12	1	2	Second Watch 3	4	5	6	7	8	9	10	Third Watch 11	12	1	2	3	4	5	6	Total Indicated	Kw.Hr. From Meter
Circuit No. 1			Indicated																										
" " 2			Kilowatts																										
" " 3																													
" " 4																													
" " 5																													
" " 6																													
" " 7																													
" " 8																													
" " 9																													
" " 10																													

Elevators

	Running Time From	to	Power Used	Number of Trips	Ave. Time One Trip
Electric No. 1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Hydraulic No. 1					

Oil, Waste and Supplies Used

Oil Kind	Gal.	Cost	Waste Kind	Lb.	Cost
No. 1			No. 1		
No. 2			No. 2		
No. 3					
No. 4					
No. 5					
Total					

Supplies Name	Amount	Unit Cost	Total Cost

Repairs and Renewals

Machine	Parts renewed or repaired	Employe	Time	Cost

Labor

Employe	Position	Time From	Time To	Hours

Remarks

FIG. 15a. COMPLETE LOG FORM FOR ENGINE ROOM PERMIT-TING COMPARISON BETWEEN WATCHES AND OTHER DETAILS OF OPERATION

The revolutions made by the pump checked against the amount of water pumped as indicated by the meter during the day will give an indication as to the volumetric efficiency of the pump, which is valuable from an operating standpoint.

The motors for driving these are directly connected to them, so that no separate item need be kept of their

Heating System

In this plant, the heating system is of the exhaust steam type with live steam used as auxiliary. In order that the proper conditions may be maintained, a record of the back pressure maintained in the heating radiators, also the pressure in the return pipe to the pump,

should be recorded. Also, when it is necessary to turn on live steam to maintain the proper temperature in the building, a different division of the cost between the power and heating service must be made. It is therefore important that we have a record of the number of hours that live steam is used in the heating system, as the amount of steam necessary for heating purposes depends upon the temperature outside and inside the building; these should be kept in the record during the heating season of the year.

Also, depending upon local surroundings and construction of the buildings, the amount of heat required is dependent to some extent upon the direction and velocity of the wind. Temperature requirements also depend

installed in this plant should indicate the time of running of each elevator and the power in kilowatt-hours consumed per day. In addition to this, the number of trips made, the number of passengers carried up and down each half hour, also the time required to make one trip are items which will help the engineer in determining the power requirements at various times of the day. The hydraulic elevator, which in this plant is a sidewalk lift, does not consume a great deal of power, so that the only items which are considered essential are the time of running and the number of trips. These items will give the engineer an idea as to the amount of water required for operating this elevator, and the time of day in which the elevator is likely to be in service.

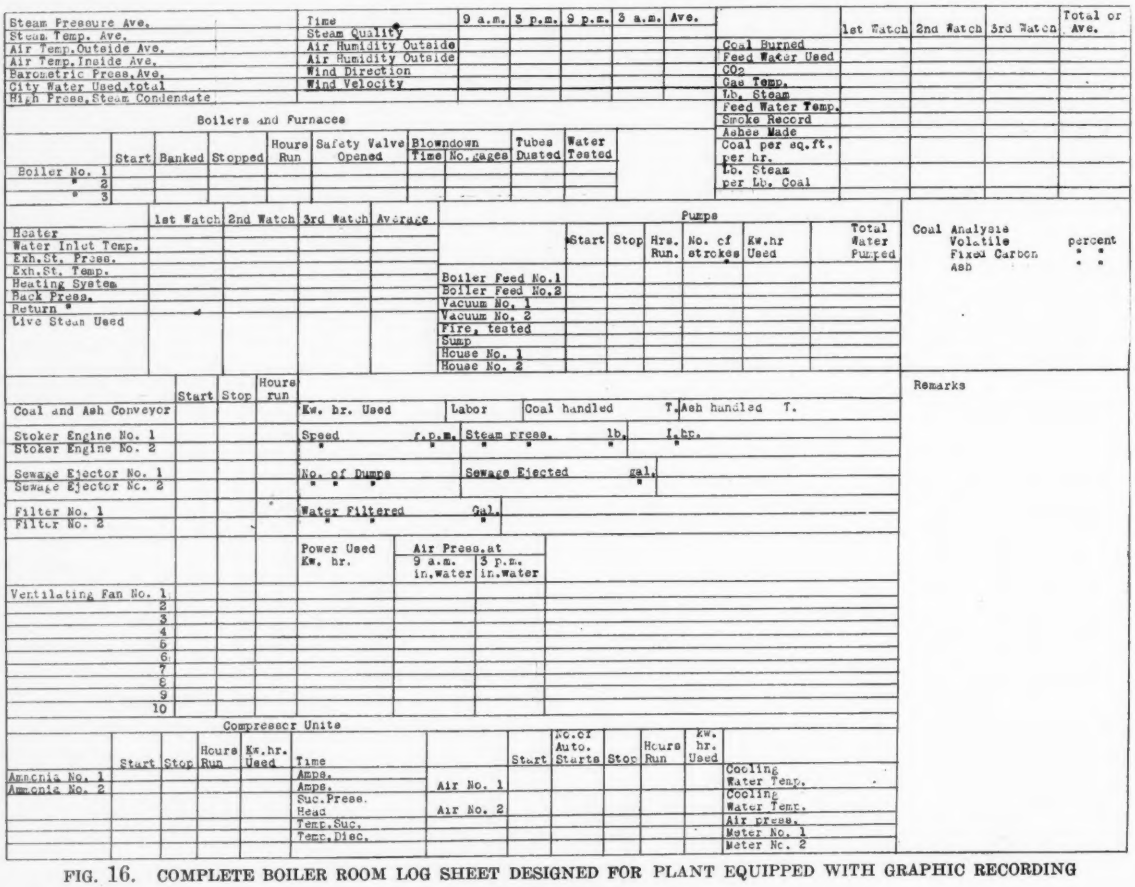


FIG. 16. COMPLETE BOILER ROOM LOG SHEET DESIGNED FOR PLANT EQUIPPED WITH GRAPHIC RECORDING INSTRUMENTS

considerably upon the humidity of the atmosphere. To give the best service, then, the engineer should have some means for showing what the humidity outside and inside the building is during the day. These may be taken from a hydrometer or a wet and dry bulb thermometer three or four times during the day. There is no other instrument which will give a better idea of the weather to come within the next few hours than the barometer. Readings every hour or so will be of considerable service to the engineer in preparing him for coming weather conditions.

ELEVATORS

THE DAILY record covering the 10 electric elevators

There are 10 ventilating fans in this plant, and they are direct connected to motors. Having practically a constant load, the items of importance are the times of starting and stopping, the kilowatt-hours consumed during the day and the pressure of the air delivered from the fans. This latter item is of convenience in showing when a duct is obstructed.

Having outlined the operating data regarding each of the principal machines in the plant, as a check to make sure no item of importance is omitted, the materials dealt with will be taken up and their course through the plant outlined.

Coal comes first in importance and in the power plant we deal with it in three ways: First, purchasing;

second, handling; third, burning. The analysis of each of these processes affecting the operation of the plant is shown in the accompanying diagram, Fig. 2, which is sufficiently clear that no further comment is necessary. A check mark is placed after each item which is taken care of in the tabulation of the plant equipment, so, to make our daily log sheet complete, the items not checked in this diagram, as well as those in the diagrams which follow, must be considered when the sheet is planned.

The processes through which water goes until it leaves the boilers as steam are purchasing, treating, heating and steam generation. These are outlined and checked as was done with the coal diagram.

In regard to steam, we must consider the amount used for various services and the conditions which affect this amount. The outline given here lists the uses and the principal influencing conditions for each use; other conditions do exist, but these have already been detailed in the tabulation of plant equipment. Steam lost by radiation is not mentioned previously, so this item should have consideration here. This may be approximated by measuring the high pressure condensate returned by means of traps and when the temperature of these are known, the total loss may be estimated.

Oil, waste and supplies are purchased and used with little or no handling done in the moderate size plant. The outline is self-explanatory. In this instance it will be noted that not one item was taken care of in the plant equipment tabulation, which shows the value of this separate angle of attacking the problem.

Repairs and renewals come in for their share of consideration and the data of importance are tabulated under that heading. The same may be said in regard to power plant labor. None of these items were considered when taking up the plant equipment, which again shows the importance of considering items entering into the variable costs as well as the equipment when planning a log sheet.

To make the log sheet most convenient, it is necessary to have the data so arranged that the items can be entered with the least amount of work. In a small plant, one log sheet kept on a desk in the engine room just inside the door from the boiler room will suffice. Here the items can be entered by those in charge of the engine and boiler rooms with the least amount of inconvenience. As the plant increases in size, this arrangement becomes awkward and separate forms are advisable. These forms naturally increase as the plant becomes divided into more departments, perhaps widely separated so that each department will require separate sheets. In order that the forms designed for the plant under consideration may be made of general use, a separate form has been made for each class of machine or item so that in planning the record sheets the individual sections may be cut down or expanded to include other data and the separate records arranged as desired by the man in charge.

Thus a form for collecting general data has been devised. On this all information which is of use in more than one department of the plant is gathered. As will be noted, much of this may be collected as records from graphic recording meters; lacking these, readings, taken at frequent intervals are desirable in order that a fair average may be secured.

Blanks for collecting data on oil, waste and supplies, repairs and renewals, and labor are the same as those given in the section on cost sheets, but repeated here to show how they are used along with other data.

In like manner, other sheets have been designed as will be noted in Figs. 3 to 13. Attention, however, is called to the three forms designed for engines and generators. These are distinctively different, but illustrate what can be done with almost any of the special forms presented here by keeping in mind the relative importance of the items possible of collection for each machine as well as the relative amount of heat loss by each piece of equipment. Thus by referring to the tabulation of plant equipment the relative importance to the

Gen. Set	Start	Stop	Hrs. Run	Total Kw.hr.	Ave. Volts	Ave. Amp.	I.hp.
No. 1							
No. 2							
No. 3							
				Volts		Amp.	
				+ −	Difference	+ −	Difference
Balancer Set No. 1							
Balancer Set No. 2							

Switchboard	Closed	Opened	Kw.hr. Total
Circuit No. 1			
" 2			
" 3			
" 4			
" 5			
" 6			
" 7			
" 8			

Oil, Waste and Supplies Used.					
Oil Kind	Gal.	Cost	Waste Kind	Lb.	Cost
No.1			No.1		
No.2			No.2		
No.3					
No.4					
No.5					
Total					

Supplies Name	Amount	Unit Cost	Total Cost

Repairs and Renewals					Labor			
Machine	Parts renewed or repaired	Employe	Time	Cost	Employe	Position	Time From To	Hours

Remarks

FIG. 16a. COMPLETE ENGINE ROOM LOG SHEET DESIGNED FOR PLANT EQUIPPED WITH GRAPHIC RECORDING INSTRUMENTS

operation of the machine of the various items is pointed out, while the table showing heat losses in the plant is convenient for determining what equipment should be given continuous study.

When it has been decided what apparatus should be subjected to continuous observation of operating efficiency and the items which are desired for this observation and the frequency of recording the items, the problem is then merely a matter of arranging the separate forms on one or more convenient log sheets and the work of planning is done.

To illustrate the method outlined three systems of operating record forms are suggested for the plant which has been under consideration.

The relative value of these records depends entirely upon the use to which they are put. If all the data collected thereon is made use of to the fullest extent, big returns will be paid on the expense of keeping them up to date.

Records for Study of Needed Improvements

Necessary Data, When and How Collected

IN GENERAL, it can be said that it is time to replace old equipment with new if, on account of greater efficiency or capacity, or both, our annual cost of production will be reduced sufficiently to justify our selling our present equipment for its scrap value.

The various items which go to make up the cost of production have already been discussed and found to be cost of fuel, labor, supplies, repairs and renewals and the various factors which constitute the fixed charges such as depreciation, annuities, interest, insurance, etc. It will be found that a unit which is not giving as low unit costs as desirable, does so because it is relatively

Repair Ticket.					
Machine	Part Repaired	Material Cost	Employe	Labor Cost	Total Repair Cost

FIG. 1. BLANK FORM FOR REPORTING REPAIRS

less efficient, than other equipment which will do the work. A comparison of the old with a new unit in this case will show that (1) physical depreciation of the old unit due to wear and tear has set in and repairs have not sufficed to bring back its former efficiency, or (2) although the old unit is in good repair and maintaining its initial efficiency, the new unit has had the benefit of improvements in design, or (3) the old unit has been burdened with longer hours of service or more load than it was originally designed to carry, repairs cannot be made in time, efficiency decreases and shutdowns are more numerous. In the first case, we say the unit has suffered physical depreciation; in the second, it has become obsolete, and in the third, inadequate.

Forms to Facilitate the Study of Improvements

For the purpose, then, of having sufficient data by which to make a decision as to whether or not improvements in equipment are required, our records must contain information bearing on the following:

(1) Cost of the present unit and its estimated economic life. If past experience has shown that new inventions are likely to be made which will cause the new unit to become obsolete in approximately a certain number of years, this will be the estimated economic life and the functional depreciation annuity determined from sinking fund tables will be based thereon. Similarly, if future growth is likely to cause the new equipment to become inadequate, its economic life will be terminated by such growth and the functional annuity computed accordingly. If experience has shown that the unit will wear out before it becomes obsolete, then the annuity will depend on its physical life. Such plant data can be obtained from manufacturers' catalogs, and blueprints from their salesmen or by specific request. They should be on file in the plant ledger.

Of importance in the consideration of improvements is the scrap value of the unit. An idea of the total salvageable scrap can be had from the shipping weights or from drawings showing the machine and the amount of iron, brass, aluminum and other metals which are used in its construction. Then if the present market value for scrap metals is known a pretty fair idea of what the machine should bring in as junk can be had. The plant ledger besides telling what was paid for our old unit should also give the cost of subsequent additions or replacements which tend to affect its value and efficiency.

As will be shown later, the cost of operation is the controlling element which determines whether a unit is economical or not. For boilers we will have to know how much coal and what kind was burned, what the average steam pressure was, and how many hours of service were rendered.

The manufacturer's guarantee of efficiency under different loads will be found in the plant record. To compare with these will be data from the efficiency test records to see whether the plant is getting as much out of the boiler under service conditions as there is reason to expect. Along with efficiencies goes capacities. The plant ledger will give the rated capacity of the boiler and the operating record the actual load curve so that we can see whether we have been forcing it unreasonably.

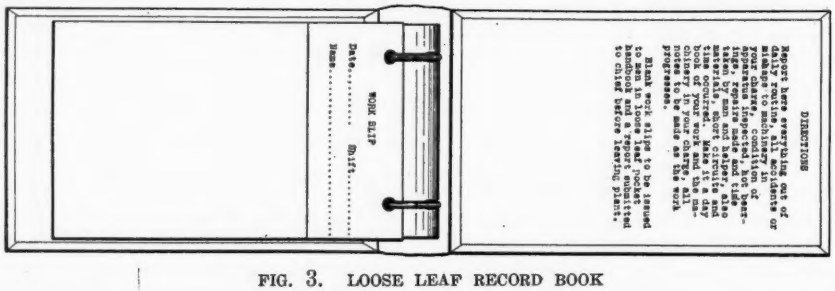


FIG. 3. LOOSE LEAF RECORD BOOK

Next in importance to the fuel costs are labor costs. The monthly operating summary will give these, together with hours in service of the equipment. We will have to divide up the wages paid to assistant engineers and firemen and pro-rate them among the different boilers according to the hours of service. As regards cost of repairs, beyond ordinary attendance such as for gage glasses, valves, etc., the cost of the material and labor we should find on the plant ledger compiled from repair tickets (Fig. 1) for this particular boiler.

The number of times the boiler is taken out of service and the reason therefor, an estimate of the monetary loss caused by each shutdown, a record of the tubes

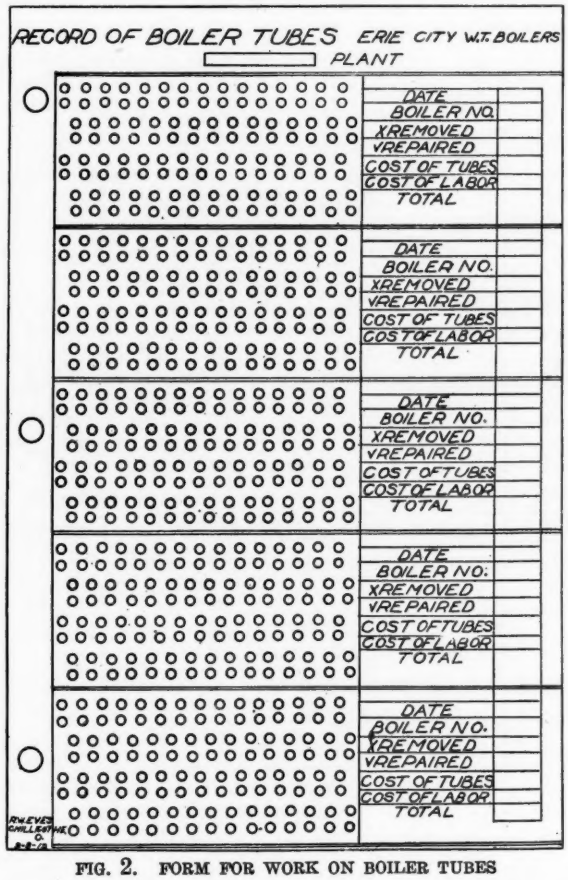


FIG. 2. FORM FOR WORK ON BOILER TUBES

cleaned (see Fig. 2) and those replaced and their cost should be an item of record in the monthly operating summary and in the plant ledger, because these will be

Boiler No. Make

line No.	Description	Year	Total	Av.	
1	Tons of Coal fired				From operating log sheets
2	Av. B.t.u. per lb.				
3	Total Cost of coal				
4	Actual boiler hp. Output				
5	Hours in Service				
6	Out of service for repairs				
a	Times				
b	Duration hrs.				
7	Yearly attendance costs				
8	Repair costs				From log sheets and plant ledger
a	Materials				
b	Labor				
c	Total				
9	Additions not classed as repairs				
10	Efficiencies at 50				From Efficiency Test Records
	various loads 75				
	Manufacturers 100				
	Guarantee 150				
	Load, per cent 200				
	250				
	300				
11	Combined 50				
	Efficiencies 75				
	based on dry 100				
	coal at 150				
	Various loads 200				
	Operating test 250				
	Load, percent 300				

FIG. 4. LOG SHEET FOR STUDY OF IMPROVEMENTS IN BOILERS

closely related to inadequacy and efficiency. Special information of this kind can be readily kept in a loose leaf record (see Fig. 3).

Items of cost listed as fixed charges, such as interest, taxes and insurance, are also needed in making a comparison of the relative economy of various kinds of units and these can be found in the annual summary of costs and pro-rated according to cost for the first cost, and

Boiler No. Make

Item	Description	Symbol	Results from	Data
1	Boiler rating Foot note (1)		Plant ledger	b.hp.
2	Rating base		" "	sq.ft.heating surface per b. hp.
3	Cost new F.O.B.factory		" "	$
4	Cost freight and cartage		" "	$
5	Installation Cost		" "	$
6	Total cost in place exclusive of foundation and setting	C	Item 3,4,& 5	$
7	Cost of foundation and setting		" "	$
8	Scrap weight, iron.		From drwgs. and shipping weight and plant ledger	
9	Market value scrap iron per lb.		Market reports	
10	Scrap value boiler	S	Item 8 x Item 9	
11	Annual interest charge	Cr	(Item 6 + Item 7 x interest rate	$
12	Annual tax charge	Et	Prorated from cost records	$
13	Annual insurance charge	Ei	Prorated from cost records	$
14	Estimated functional economic life of boiler when new	N	From "life" tables	yr.
15	Functional Depreciation Annuity	F(C-S)	See Foot Note 2	
16	Av.tons of coal fired annually this boiler		Impt. log	tons
17	Av.b.t.u. in coal fired annually in ten thousands		Impt. log	B.t.u.
18	Av.annual cost of coal fired this boiler	Ef	Impt. log	$
19	Av.annual b.hp.hr. output	Y	Impt. log	b.hp.hr
20	Av.annual fuel cost per b.hp.hr.output		Item 18 ÷ Item 19 '	$
21	Av.hr.in service per year		Impt. log	hr.
22	Av. hr. out of service for repairs per year		Impt. log	hr.
23	Estimated annual loss on account of shutdowns	Ew	Impt. log	$
24	Av.annual attendance costs	Et	Impt. log	$
25	Av. annual attendance cost per b.hp.hr. output		Item 24 ÷ Item 19 '	$
26	Av.annual fuel and attendance cost per b.hp.hr. output		Item 20+ Item 25	$
27	Av.annual repair costs	Ex	Impt. log	$
28	Av.annual repair costs per b.hp.hr. output		Item 23 ÷ Item 16	$
29	Estimated physical life of boiler when new		From "life" record of this & similar boilers	yr.
30	Physical depreciation annuity	D(C-S)	Sinking fund annuity based on value(Item 6-Item 10) and on life Item 29	$
31	Percentage of manufacturer's guarantee of combined efficiency based on dry coal attained at various loads as determined by test	Percent rated cap. 50 75 100 150 200 250 300	Impt.log	per cent

Recapitulation.

a	Interest on investment	Cr	Item 11	
b	Annual functional depreciation annuity	F(C-S)	Item 15	
c	Equated (3) annual operating expenses	Ef + Ew + Ei + Ex + Et + Es + D(C-S)	Item 18 + Item 23 + Item 24 + Item 27 + Item 12 + Item 13 + Item 30	
d	Av.annual boiler horsepower hour output	Y	Item 19	
e	Av.annual cost of producing 1 boiler horsepower hour		(Item a + Item b + Item c) ÷ Item d	
f	Av.combined eff.at usual load		Item 31	
g	Ratio of cost of repairs to first cost		Item 27÷Item 3	
h	Estimated annual cost future repairs		Based on Item 27	
i	Av.yearly load factor based on 24 hr. maximum			

(1) A.S.M.E. code

(2) The rate "F" of the functional depreciation annuity is obtained from the sinking fund formula

$$F = \frac{r}{(1+r)^N - 1}$$

in which

F = Amount set aside annually to accumulate $1.00 at compound interest in N years
r = compound interest rate
N = Estimated functional economic life (Item 14)

the total annuity is then:

$$F(C-S)$$

where (C-S) is the depreciable value of the investment in dollars.

(3) Equated on a sinking fund basis. Method of procedure shown in analysis for improvements which see. For most purposes the arithmetical annual average will be found sufficiently accurate and can be used instead.

FIG. 5. SUMMARY AND RECAPITULATION SHEET FOR PRESENT EQUIPMENT

floor space for equipment and real estate taxes respectively for the second, and according to cost for the third.

Suppose, then, that it is contemplated to replace a particular boiler as the service has not been as satisfactory as desirable. We gather together our records. From the records the data pertinent to this particular

boiler are taken. In order to analyze the data, it is well to arrange it in a form similar to that shown in Fig. 4. The record should be filled out for each year of life of the boiler and can then be summarized on another sheet. From the summary a recapitulation can be prepared Fig. 5 which can be compared with a similar summary prepared for a new boiler.

In gathering statistics concerning the new boiler, great care must be exercised to insure that the data are reliable and comparable with those of the old unit. The rating base must be carefully noted, as not all manufacturers use the same base. Freight and cartage costs are part of the expense and these can be estimated on a basis of shipping weights and freight rates. If special provision must be made in the building for taking the new unit in, this should be charged to foundation costs if a new foundation is necessary; or if not, a separate charge can be made. Scrap value can be estimated as

Manufactured by

Item No.	Description	Results from	Data
1	Boiler rating	Manufacturers catalogue and prints	b.hp.
2	Rating base	As above	sq.ft. heating surface per b.hp.
3	Cost F.C.B. factory	From catalogue or salesman's price list.	$
4	Cost freight and cartage	Estimated from shipping weight	$
5	Installation cost	Estimate based on previous construction	$
6	Total cost in place exclusive of foundation and setting	Item (4 + 5 + 6)	
7	Cost of foundation and setting if required	Estimated from blue prints	
8	Scrap weight	From manufacturer's records	lb.
9	Market value scrap iron per lb.	From market reports	$
10	Scrap value boiler	Item 9 X Item 10	$
11	Annual interest charge on first cost	Item 7 + Item 8 X interest rate	
12	Annual tax charge	Estimated	
13	Annual insurance charge	Estimated	
14	Estimated economic life of boiler	From "life" tables same class units	yr.
15	Functional depreciation annuity	Sinking fund annuity based on value (Item 6 -Item 11) and life of Item 14	$
16	Annual b.hp. hr. output Y at 100 per cent rating	Estimated	b.hp.
17	Fuel cost per b.hp. hr. based on coal ----B.t.u. --at$ per ton	Manufacturer's guarantee	$
18	Total annual fuel cost Kf	Item 16 X Item 17	$
19	Total attendance cost Ka	Estimated	$
20	Total repairs cost Kx	Estimated	$
21	Estimated physical life of boiler	Comparison with similar boilers	yr.
22	Physical depreciation annuity	Sinking fund annuity based on value (Item 6- Item 10) and life of Item 21	
23	Manufacturer's guarantee of combined efficiency based on dry coal at various load factors: Percent load 50, 75, 100, 150, 200, 250, 300	From Manufacturer's Specifications	Per cent eff.

FIG. 6. SUMMARY SHEET FOR NEW EQUIPMENT

described for the old unit. Annual interest, tax and insurance charges can be estimated on the new cost and on the corresponding charges for the present unit. Many of the other statistics are compiled as for the old boiler; but the estimated annual costs for fuel, labor and repairs should be carefully scrutinized to see that they are not underestimated.

A log sheet for data concerning the new boiler is hardly necessary. The summary sheet for the new unit shown in Fig. 6 will ordinarily suffice. It is very similar to that shown in Fig. 5. From Fig. 6 a recapitulation, not shown, can be made which will be similar in most respects to that shown in Fig. 5. A similar summary and recapitulation should be made for each make of boiler which is assumed as one likely to be a better boiler to fit the operating requirements than the one in use. The analysis described in a later section will show how to compare the statistics for the different boilers.

The general idea of keeping an improvements log sheet on which to record data used in the study of the necessity for improvements, and then totaling and averaging the data for several years and placing them in a summary and thence to a recapitulation sheet will be found useful for general application.

Engine No. Make

Item	Description	Results from	Data
1	Rated brake horsepower	Plant ledger	br.hp.
2	Cost F.C.B. factory	" "	$
3	Cost freight and cartage	" "	$
4	Installation cost	" "	$
5	Total cost in place exclusive of foundation C	Items (2 + 3 + 4)	$
6	Cost of foundation and setting	Plant ledger	$
7a	Scrap weight iron	" "	lb.
b	" " brass	" "	lb.
c	" " miscellaneous	" "	lb.
8a	Market value scrap iron per lb.	Market reports	$
b	" " " brass "	" "	$
c	" " " miscellaneous per lb.	" "	$
9a	Scrap value iron	Items (7a x 8a)	$
b	" " brass	Item 7b x 8b	$
c	" " miscellaneous	Item 7c x 8c	$
10	Total scrap value engine S	Items (9a + 9b + 9c)	$
11	Annual interest charge Cr	Item 5 x Interest rate	$
12	Annual tax charge Et	Prorated from cost records	$
13	Annual insurance charge Ei		$
14	Estimated economic functional life of engine N	"Life" tables	yr.
15	Functional depreciation annuity F(C-S)	Sinking fund annuity based on value (Item 5 - Item 10) and life of Item 14	$
16	Av.lb. of dry steam consumed annually	Improvements log	lb.
17	Av.annual cost of 1 lb. of dry steam	Improvements log	$
18	Av.annual cost of steam consumed Ef	Item 16 x Item 17	$
19	Av.annual br.hp.hr. output Y	Improvements log	br.hp.hr.
20	Av.annual cost of steam per br.hp.hr. output	Item 18 ÷ Item 19	$
21	Av.annual hours in service	Improvements log	hr.
22	Av.annual hours	Improvements log	hr.
23	Out of service for repairs. Estimated annual loss account of shutdowns Ew	From log	$
24	Av.annual prorated attendance costs Ea	Improvements log	$
25	Av.annual repair costs Ex	Improvements log	$
26	Av.annual steam,attendance and repair costs per br. hp. output	Item (18 + 24 + 25) ÷ 19	$
27	Estimated physical life of engine from date when first acquired.	From life (1) records of this and similar engines	yr.
28	Physical depreciation annuity D(C-S)	Sinking fund annuity based on value (Item 5 - Item 10) and life Item 27	$
29	Percentage of manufacturer's guarantee of thermal efficiency referred to br.hp. attained at various loads as determined by operating test: Percent load 40, 60, 80, 100, 125, 150, 175, 200	Test records	per cent
30	Av. yearly load factor based on 24 hr. max.	From improvement log	per cent

(1) Note what text says about "life" tables as regards physical life.

FIG. 7. SUMMARY SHEET FOR STUDY OF IMPROVEMENTS IN ENGINE EQUIPMENT

The method of compiling the data for a steam engine using this method of organizing the work has been shown in Figs. 7 and 8. The log sheet is not shown nor the corresponding summary and recapitulation forms for

Item	Description	Results from	Data
1	Interest on investment Cr.	Item 11	
2	Annual functional depreciation annuity F(C-S) (1)	Item 15	
3	Equat. (1) annual operating expenses (Ef + Ei + Ew + Ex + Et + Ei + D(C-S)	Item 18+ Item 23+ Item 24+ Item 25+ Item 12+ Item 13+ Item 27	
4	Av.annual brake horsepower hour output Y	Item 19	
5	Av.yearly load factor based on 24 hr. max.	Item 30	
6	Ratio of annual cost of repairs to cost new	Item 25 ÷ Item 2	
7	Estimated annual future repairs		
8	Av.annual cost of producing 1 br.hp.hr.	Item 1+ Item 2+ Item 3+ Item 4	From recapitulation
9	Estimated total demand br.hp.hr. for ensuing year		br. hp.hr

(1) As will be explained in the analyses the functional depreciation factor for an old plant becomes zero when comparing the old plant with a new one. However, for computing the unit cost of production this annuity must be considered.

FIG. 8. RECAPITULATION OF SUMMARY SHEET FOR STUDY OF ENGINE IMPROVEMENTS

the new equipment to be considered. These in many cases will include not only steam engine, but internal combustion engines and turbines.

WALL STREET JOURNAL announces that several million tons of coal have been displaced by fuel oil in New England out of total annual coal requirements of 60,000,000 tons in that section. This displacement of coal refers only to industrial users.

Analysis of Cost Records

Distribution of Expenses to Different Services and Calculation of Unit Costs

HAVING planned the operating records so that it is possible to ascertain the amount and value of the various items which enter into the cost of producing power, heat, etc., and the size of the corresponding output, it remains to take the different items and distribute them among the various commodities produced so that each is charged with the equitable portion of the total cost incurred in its production.

For the purpose of showing how the various costs are computed and distributed, a certain power plant is assumed whose cost is known, that certain records which will give us the fixed charges such as interest, taxes, cost of management, etc., are accessible and that complete monthly records of operating costs and output have been kept.

With the addition of several additional columns the form shown in Table I on page 8 will nicely suit the purpose for analysis. The operating records show the following items of cost summarized monthly:

Coal, ash removal, oil, packing waste, general supplies, labor, repairs, and renewals.

A record has also been kept of the kilowatt-hours output at the switchboard and the amount of water evaporated. This power plant, as it supplies a machine shop with heat, light and power, has arranged its records to show the average outside temperatures and the hours in which exhaust steam and live steam are used for heating.

The unit prices are those of 1919, $5 being paid for a ton of coal.

The monthly cost of the items has been tabulated as shown in Table I and gives us the following annual costs:

Coal	$4072.50
Ash removal	48.90
Oil	153.30
Packing	32.06
Waste	14.52
General supplies	138.58
Labor	4370.81
Repairs	80.08
Renewals	311.78
Total operating costs	$9222.53

Taking up next the subject of fixed charges, we find them to consist of interest, plant insurance, liability insurance, taxes, functional depreciation annuity, and management.

Interest is based on first cost of original equipment plus the cost of betterments and additions, the assumption being that physical depreciation has been taken care of by renewals and repairs so that physically its value as a going proposition is equal to its original value. Included in the cost of the equipment must be freight, cartage and installation expenses.

The plant ledger shows the plant to consist of the following equipment whose present value is as shown:

Engines	$ 6000
Boilers and stokers	9000
Boiler auxiliaries	1000
Piping	3680
Generators and switchboards	6900
Coal handling machinery	1500
Building, engine foundations and stack	15,000
Total plant value	$43,080

TABLE I. TABULATION OF MONTHLY COSTS

	Coal	Ash removal	Oil	Packing	Waste	Genl. Supp.	Labor	Rep.	Renewals	Kw.hr. produced at switch	Steam produced lb.	Av. Outside Temp.	Hours Exhaust Steam on	Hours live steam on
Jan.	504.00	6.00	14.17	2.46	1.29	18.71	396.51			27,420	1,811,000	20	420	440
Feb.	465.00	5.60	12.83	4.18	.85	14.38	365.88	15.38		25,230	1,673,500	26	342	412
Mar.	371.00	4.50	15.16	1.82	1.98	16.22	368.37		137.00	20,720	1,336,000	34	400	300
Apr.	343.00	4.10	11.73	5.17	.75	8.17	350.19			20,700	1,235,000	46	340	200
May	271.00	3.30	10.48	1.48	.54	6.88	371.51	23.60		19,530	976,500	53	250	
June	222.00	2.70	9.68	1.37	.80	14.97	356.30	14.10	83.00	15,980	799,000	69		
July	206.00	2.50	11.09	1.04	.72	10.19	347.19			14,850	742,500	77		
Aug.	174.00	2.10	10.19	2.39	1.58	7.83	340.39			12,540	627,000	84		
Sept.	212.00	2.50	13.83	3.68	2.23	3.34	345.30		91.78	15,270	763,500	70		
Oct.	289.50	3.50	14.76	4.97	1.02	6.97	368.98	7.80		20,820	1,041,000	55	280	
Nov.	437.00	5.20	13.10	2.72	.96	14.10	371.51			27,450	1,572,500	38	380	200
Dec.	578.00	6.90	16.28	2.88	1.73	16.32	389.70	19.20		32,800	2,080,000	26	420	440
Total	4072.50	48.90	153.30	32.06	14.52	138.58	4370.81	80.08	311.78	253,310				

Interest on first cost at 6 per cent = $43,080 \times 0.06 =$ $2584.80.

Insurance premiums on plant and equipment, the records show to average 2 per cent of first cost annually. Plant insurance then will be $43,080 \times 0.02 =$ $861.60.

Workmen's liability insurance on power plant labor for an isolated plant is based on the weighted average insurance assessed on the wages of the workmen employed in the manufacturing plant of which it forms a part. This, being a machine shop, carries a charge of 1.8 per cent of wages. As the labor costs amount to $5580.81, the liability insurance will be $5580.81 \times 0.018 =$ $100.45.

Taxes are ½ per cent of full assessed value, or $43,080 \times 0.005 =$ $215.40.

The functional depreciation annuity which is to take care of obsolescence and inadequacy found by consulting sinking fund tables is the amount to be set aside annually to draw compound interest, so that at the end of the functional life of the unit the amount will equal $1 for each dollar of the depreciable value of the unit.

In this case a compound interest rate of 4 per cent is used. The depreciable value is equal to the first cost minus scrap value, which is the market price of the scrap after deducting the cost of removal. The life expectancy

differs widely according to the opinion of many authorities and what appears to be a fair average for the equipment in question is shown. The records show the amount of scrap material in the various machines, which have been multiplied by the market value of scrap, from which product is deducted the estimated cost of removal.

TABLE II. SHOWING METHOD OF COMPUTING FUNCTIONAL DEPRECIATION ANNUITY INTEREST COMPOUNDED ANNUALLY AT 4 PER CENT

Item	Cost in place (1) incl. freight and installation	Scrap value	Depreciable value	Functional life	Functional Depreciation Annuity	Amt.
Engines	6,000	600	5400	25	2.40	129.00
Boilers & Stokers	9,000	900	8100	20	3.38	273.16
Boiler Auxiliaries	1,000	50	950	18	3.90	37.05
Piping	3,680	180	3500	15	5.00	175.00
Generators & Switchboard	6,900	360	6540	20	3.36	120.08
Coal handling Machinery	1,500	150	1350	10	8.33	112.46
Building, foundations, stack.	15,000	1500	13500	40	1.05	141.75
Total	43,080		39350			987.50
Av. based on depreciable value					3.98	

(1) Including betterments and additions

Inasmuch as the functional life varies as between the different classes of units the annuity for each must be computed independently. To illustrate the procedure, Table II is given.

The first column shows the first cost of equipment; the scrap value is shown in the second column, and depreciable value, third column, is then readily found by subtracting values in column 2 from corresponding costs in column 1. The source of the other figures is evident.

The total functional depreciation annuity is then shown to be $987.50, which amounts to 3.98 per cent on the total depreciable value and corresponds to an average functional life of practically 18 yr. for the entire plant.

TABLE III. SUMMARY OF FIXED CHARGES

Interest on first cost at 6%	= 43,080	x 0.06	=	$2,584.80
Plant insurance at 2%	= 43,080	x 0.02	=	861.60
Liability insurance 1.8% of labor cost	= 4,370.81	x 0.018	=	78.68
Taxes 1/2% on first cost	= 43,080	x 0.005	=	215.40
Functional depreciation annuity			=	987.50
Cost of management 1/4 hr. daily of 8 hr. day.	= 6,000	x 1/32	=	187.50
Clerical expense			=	150.00
	Total			$5065.48

The distribution of the management expense will be executed as follows:. The general plant superintendent, who also is in direct charge of the power plant, spends on an average 15 min. every day in going over the records and giving instructions to the engineer who acts in the capacity of foreman in the power plant. The superintendent works 8 hr. a day and receives a salary of $6000 a year. Prorating his time gives $\frac{1}{4} \times \frac{6000}{8} =$ $187.50. In addition to the manager's time, there is a small amount of clerical work for the ordering of fuel, supplies, repairs, etc., and sundry other work which is estimated to cost $150.

In Table III are summarized the fixed charges which total up to $5065.48.

The total operating costs and fixed charges, therefore, amount to $9222.53 plus $5065.48 or $14,288.01 for power and heating.

The summary shows the total annual output in kilowatt-hours at the switchboard to be 255,310. Therefore the unit cost per kilowatt-hour, including heating, is $14,288.01 ÷ 255,310 = 5.6 cents.

The unit cost of production given above serves many purposes and the various items which enter into its make-up can be watched so that discrepancies may be investigated and proper corrective measures instituted. There will, however, come a time when the engineer will be asked for the actual cost of producing the power only, so that it may be compared with the cost of purchased power or with the cost of power produced in a similar plant.

In the separation of costs between steam used for power purposes and that used for heating, certain of the fixed costs may be rightfully considered as due to power only and others to both power and heating. The operating charges may be distributed similarly.

It is logical, therefore, to divide the fixed cost of plant so that equipment which is used only for generating power such as engines, turbines, switchboards, etc., and which are not needed for purely heating load would be charged directly against power. On the other hand, boilers and stokers and the building itself are needed for both purposes and must be prorated.

Operating expenses can also be divided up. Such items as oil, packing and waste can be charged to power. General supplies will be divided equally between engine and boiler room. The plant ledger shows that of

TABLE IV. TABULATION OF YEARLY OPERATING EXPENSES

	Total coal, ash removal & labor costs	Total steam produced	Steam to Engine: Charge to power	Steam to Engine: Charge to heating	Steam to heating system only	Proportion to power	Proportion to heat	Total cost to power	Total cost to heat
Jan.	$ 905.51	$1,811,000	$274,200	$1,026,800	$440,000	$15.10	$84.90	$ 136.73	$ 768.78
Feb.	836.48	1,673,500	252,300	1,009,200	412,000	15.05	84.95	126.19	710.29
Mar.	743.87	1,336,000	207,200	828,800	300,000	15.48	84.52	115.15	628.72
Apr.	697.29	1,235,000	207,000	828,000	200,000	16.75	83.25	116.80	580.49
May	645.81	976,500	195,300	781,200		20.00	80.00	129.16	516.65
June	581.00	799,000	799,000			100.00	0	581.00	
July	555.69	742,500	742,500			100.00	0	555.69	
Aug.	516.49	627,000	627,000			100.00	0	516.49	
Sept.	559.80	763,500	763,500			100.00	0	559.80	
Oct.	661.96	1,041,000	208,200	832,800		19.96	80.04	132.13	529.83
Nov.	813.71	1,572,500	274,500	1,098,000	200,000	17.45	82.55	141.99	671.72
Dec.	974.60	2,080,000	328,000	1,312,000	440,000	15.77	84.23	153.69	820.91
	8492.21							3264.82	5227.39

Percentage to power = 38.5
" heating = 61.5
100.0

TABLE V. OPERATING EXPENSE DISTRIBUTION

	Power	Heating
Coal, ash removal and labor	$3264.82	$5227.39
Oil	153.30	
Packing	32.06	
Waste	14.52	
General supplies	69.29	69.29
Repairs and renewals	316.49	75.37
Total	3850.48	5372.05

the repairs, 49.31 is for the engines and generators, while the remainder, 30.77, is for repairs on boilers, feed pumps, and piping. From the same source we find that the $137 and $83 renewal items belong to the engine room and the $91.78 item belongs to the boiler room. All items chargeable to the boiler room will be prorated to power and heating as described in the following analysis for coal:

The remaining undivided operating expenses are the costs of coal, ash removal and labor. The first two, from their nature, can be considered together.

Manifestly, since no exhaust steam is required in the summer months of June, July, August and September, the entire cost of the coal and of the ash removal must be charged against power production. During the remaining 8 mo. of the year, a quantity varying between 60 and 100 per cent of the exhaust steam is used for heating, while in addition live steam must be used varying in amount with the outdoor temperature and the number of hours that exhaust steam from the engine is available. The distribution of the coal costs as between the power and heat services must necessarily be somewhat arbitrary, but inasmuch as about 10 to 20 per cent of the total heat units put into the steam are used in power generation while the remaining 80 to 90 per cent are returned to the heating system, 20 per cent of the

TABLE VI. DISTRIBUTION OF PLANT INVESTMENT AND FUNCTIONAL DEPRECIATION ANNUITY

	Plant Investment			Depreciation Annuity		
	Total	Charge to power	Charge to heating	Total	Charge to power	Charge to heating
Engines	$ 6000	$ 6000.00		$ 129.00	$129.00	$
Boilers & Stokers	9000	3465.00	$ 5535.00	273.16	105.00	167.16
Boiler Auxiliaries	1000	385.00	615.00	37.05	14.25	22.80
Piping	3680	1416.80	2263.20	175.00	67.50	107.50
Generator & Switchboard	6900	6900.00		120.08	120.08	
Coal handling Machinery	1500	577.50	923.50	113.46	43.40	69.06
Building, foundations & Stack	15000	5775.00	9225.00	141.75	54.60	87.15
Total	43080	24519.30	18560.70	987.50	533.83	453.67

cost of the steam going to the engine during the heating season can arbitrarily be charged to power generation, while the remaining 80 per cent should be charged to heating. Examination of the steam consumption during the month when no exhaust steam is used will show that in the case of the plant under consideration an average of 50 lb. of steam are used for each kilowatt-hour of power produced. This amount can, therefore, be assumed, as the steam consumption of the engine during the other 8 mo. and prorated to power and heating as explained above. The remaining steam produced must then be considered as used solely for heating and will be distributed accordingly.

As respects labor costs, the general opinion of authorities indicates that it should be prorated in the same proportion as the steam consumption and this will be the method used in this analysis.

Separation of Operating Costs

Taking up coal, ash removal and labor costs which are lumped together and prorated according to steam consumption, it will be found that of the 1,811,000 lb. of steam produced in January 1,371,000 lb. are used to supply steam for the engine, assuming 50 lb. of steam per kilowatt-hour. Of this 1,371,000, 20 per cent, or 274,200 lb., is charged to power, the remaining 80 per cent, or 1,026,800, being charged against heating. The remaining steam not accounted for by the engine, 1,811,000 — 1,371,000 = 440,000 lb. is then directly chargeable to heating only.

For the month of January, then, there is a total of 274,200 lb. charged to power, or 15.10 per cent of the total steam generated. Multiplying the total cost, labor and ash handling costs by 0.151, we have $136.73 as the cost of these items for power. The remaining 84.90 per cent, or $768.78, is the cost for heating.

As explained before, the entire cost in the months when no heat is used is charged to power. Table IV

TABLE VII. SUMMARY OF FIXED CHARGES

	Power	Heating
Interest on first cost at 6%		
Power = 24519.30 x .06	$1471.16	
Heating = 18560.70 x .06 =		$ 1113.64
Plant insurance at 2% =	490.36	371.22
Liability insurance at 1.6% of labor cost		
Power labor = 4370.81 x 36.5 = 1682.76 x 0.18=	30.30	
Heating labor 4370.81 x 61.5 = 2688.06 x 0.18=		48.38
Taxes at 1/2% first cost	122.60	92.80
Functional depreciation annuity	533.83	453.67
Cost of management, 1/4 hr. daily of 8 hr.day at $6000 per year = 187.50 total	72.30	115.20
Clerical expense total 150.00	57.75	92.25
	$2778.32	$2287.16

shows the tabulation of these costs for the entire year, of which $3264.82, or 38.5 per cent, goes to power and $5227.39, or 61.5 per cent, to heating.

Repairs and renewals items totaling $122.55 and charged to the boiler room will be prorated on the same percentage. This gives $122.55 \times 0.385 = \$47.18$ for power and $122.55 \times 61.5 = \$75.37$ for heating. Adding to the former, the $49.31 engine room repair and the $137.00 and $83.00 engine room renewals makes a total all told of $316.49 charged to power.

Table V shows the distribution of the operating expenses.

Distribution of Fixed Charge

Of the plant, the engines, $6000, and generators and switchboards, $6900, or a total of $12,900, are used solely for power production. The boilers, stokers, piping, the building, etc., totaling $30,180, are used for both power and heating and will be distributed in the same proportion as the coal and labor.

TABLE VIII. DISTRIBUTION OF TOTAL CHARGES

	Power	Heating
Operating Costs	$3850.48	$5372.05
Fixed charges	2778.32	2287.16
	$6628.80	$7659.21
Total Kw.hr. power = $255,310		
Cost per Kw. hr. = 6628.80 ÷ 255310 = $0.026		

The distribution of these and the other fixed charges as outlined in previous paragraphs is shown in Tables VI and VII. The first shows how the plant investment costs are divided and likewise how the functional depreciation annuities are taken care of. Table VII summarizes all the fixed charges.

In Table VIII a recapitulation of operating cost and fixed charge distribution against power and heating shows that the total cost of production of power is $6628.80, which, for a total production of 255,310 kw.-hr., nets a unit cost of 2.6 cents per kilowatt-hour.

Analyses of Tests

Methods of Comparing Test Data

TESTS having been conducted and the summary sheets worked out as indicated in a previous article, it is frequently a perplexing problem to determine how these data can best be used. The object of most tests of power plant equipment is generally to determine whether or not the equipment is holding up to its standard record of efficiency and if not, to determine why not. Standard test codes have been devised for the sole purpose of making comparison between equipment run under somewhat different conditions, yet these codes are faulty in some respects, so that it cannot be said that a machine which shows a higher efficiency than another is the more economical, unless the conditions of operation are substantially the same or just corrections can be made to bring the data on a parallel basis for comparison.

As a guide in making comparisons of power plant machinery, the accompanying classification of standards of efficiency and economy, which have been adopted by the American Society of Engineers, shows the items with which to begin the analysis.

STANDARDS OF EFFICIENCY AND ECONOMY

a Boilers	Relation between B.t.u. absorbed by boiler per lb. of dry coal and calorific value of 1 lb. dry coal. (Efficiency of boiler, furnace and grate.) Relation between B.t.u. absorbed by boiler per lb. of combustible burned and calorific value of 1 lb. combustible. (Efficiency based on combustible.)
b Reciprocating Steam Engines	(1) B.t.u. per i. hp.-hr. (2) B.t.u. per brake hp.-hr. (3) Ft.-lb. of net work per B.t.u. (4) Thermal efficiency referred to i. hp. (5) Thermal efficiency referred to br. hp. (6) Rankine cycle ratio referred to i. hp. (7) Rankine cycle ratio referred to br. hp. (8) Lb. of steam per i. hp.-hr. (9) Lb. of steam per br. hp.-hr.
c Steam Turbines	(1) B.t.u. per br. hp.-hr. (2) Ft.-lb. of net work per B.t.u. (3) Thermal efficiency. (4) Rankine cycle ratio. (5) Lb. of steam per kw.-hr.
d Turbo-generators (including engine-driven generators)	(1) B.t.u. per kw.-hr. (2) Ft.-lb. of net work per B.t.u. (3) Thermal efficiency. (4) Rankine cycle ratio. (5) Lb. of steam per kw.-hr.
e Pumping Engines	(1) Ft.-lb. of work per million B.t.u. (2) Ft.-lb. of net work per B.t.u.
f Compressors, Blowers, and Fans	(1) B.t.u. per net air hp.-hr. (2) Ft.-lb. of net work per B.t.u. (3) Lb. of steam per net air hp.-hr. (4) Lb. of steam per 1000 cu. ft. of free air compressed to 100 lb. gage pressure reduced to atmospheric temperature.
g Complete Steam Power Plants:	
Plants in General	(1) Lb. of coal as fired per i. hp.-hr. (2) Lb. of steam per i. hp.-hr. (3) Heat units in fuel consumed per i. hp.-hr.
Electric Plants	(1) Lb. of coal as fired per kw.-hr. (2) Lb. of steam per kw.-hr. (3) Heat units in fuel consumed per kw.-hr.
Pumping Plants	(1) Ft.-lb. of work per million B.t.u. (2) Lb. of coal as fired per water hp.-hr.
Air Machinery Plants	(1) Lb. of coal as fired per air hp.-hr. (2) Lb. of steam per air hp.-hr.

It is essential, however, in the comparison of test data from different units or from the same unit collected at different times, that consideration be given to a number of items besides the mere comparison of the efficiency figures. Many items collected during a test affect the efficiency yet do not enter into the efficiency calculation, and no means have as yet been devised for making corrections which will put the tests on a comparable basis. It is a consideration of these items which will be taken up in this article on analysis of tests.

Boilers

Referring to the boiler test summary on pages 21 and 22, it is not likely that the coal used to make a test today is of exactly the same quality and heat value as that used in making a test of the same boiler 3 yr. ago, while the heat value of the coal does enter into the calculation of the efficiency; whether or not that heat comes principally from the volatile combustible matter in the coal or from the fixed carbon does not enter into the efficiency calculation, yet this fact has great influence on the results obtained. Likewise the percentage of moisture, ash and fusing point of ash have influences on the efficiency of the boiler, furnace and grate which do not justify the comparison of the condition of the units as it is now and as it was, nor can such a test be considered a just comparison of the adaptability of the furnace to the coal, as the condition of the boiler is not likely the same as it was during the former test.

Again, while the weight of water fed to the boiler enters into the efficiency calculation, the manner of feeding that water, whether continuously or intermittently, has an effect for which no correction factor has been devised.

That the force of the draft, thickness of the fuel bed and combustion per square foot of grate surface have influences on the combined boiler, furnace and grate efficiency will not be denied, yet who can say positively that with a certain definite change in any one of these conditions the efficiency can be changed by a definite factor when the tests show other variables?

In the comparison, then, of boiler tests, the fairest method is to start with efficiencies, work back through the economic results, horsepowers, pressures, temperatures, etc., making note of the differences, and with the items which show appreciable variation set out by themselves, an idea can be had of the relative effects of many of these on general results by referring to the charts and tables in the back of the issue.

As a concrete example of this method of examining boiler tests, a comparison is made here of tests reported by the American Engineering Co., conducted for substantially the same purpose on similar equipment of nearly the same capacity, but under somewhat different conditions.

TEST RECORD SHEET

Report of test on———— water tube boiler.
Boilers equipped with 7-retort underfeed stokers.
Purpose of test—Capacity.

	1st	2d
1. Run from .....8 a. m. to 9 a. m.		
2. Duration of test.....hours..	1	4
3. Number of boilers used.....	1	1
4. Type of boiler.....	—	—
5. Number of tubes.....	312	
6. Diameter of tubes.....	4"	
7. Water-heating surface.....sq. ft..	6,270	6,132
8. Superheating surface.....sq. ft..		1,200
9. Grate surface.....sq. ft..	94.5	91
10. Ratio grate surface to water-heating surface .....1 to..	66.7	67.4
11. Steam pressure, gage lb. (1) 198; (2) 122.9.....abs. lb..	212.7	137.6
12. Atmospheric pressure .....lb..	14.7	14.7
13. Draft suction at uptake.....in..	.7	.7
14. Draft suction over fire.....in..	.05	.056
15. Pressure in tuyere box.....in..	4.1	3.31
16. Blower pressure .....in..		
17. Av. temperature, at blower..Deg. F..	68	
18. Furnace temperature .....Deg. F..		
19. First pass temperature.....Deg. F..		
20. Second pass temperature....Deg. F..		
21. Third pass temperature.....Deg. F..		
22. Average temp., flue gases...Deg. F..	540	510.3
23. Average temp., feed water..Deg. F..	68	184
24. Average temp., steam (1) Tp 397; (2) 351.76.....Deg. F..	526	457.06
25. Fan speed .....r.p.m..	457	
26. Stoker engine speed.....r.p.m..	457	417
27. Name of fuel.....Springfield, Illinois		Illinois Bituminous
28. Size of fuel.....Slack		Screenings
Proximate analysis:		
Moisture	12.0	15.76
Volatile matter	26	
Fixed carbon	45.6	
Ash	16.4	14.72
B.t.u.:		
Fired	9,840	9,976
Dry 11,185		11,844
Combustible 12,100		14,296
Ash:		
Per cent comb. in refuse.....		10.98
Refuse per cent coal fired.....		16.5
Flue gas:		
CO_2 first pass.....	15.5	
CO_2 flue		14.19
O		3.99
CO		.025
N, etc.....		81.79
29. Coal burned total run, as fired...lb..	7,400	24,471
30. Water evaporated total run, actual .....lb..	42,700	153,435
31. Coal burned per hour, as fired...lb..	7,400	6,118
32. Coal burned per hour, dry.....lb..	6,520	5,154
33. Coal burned per hour per sq. ft. grate surface, as fired.....lb..	78.5	67.2
34. Coal burned per hour, per retort, as fired.....lb..	1,057	875
35. Total weight of refuse.....lb..		3,971
36. Total weight of combustible burned .....lb..		16,643
37. Water evaporated per hour, actual .....lb..	42,700	38,359
38. Factor of evaporation.....	1.272	1.1318
39. Water evaporated per hour (f & a 212 deg).....lb..	54,400	43,414
40. Degrees superheat	129	105.3
41. Horsepower builder's rating.....	627	613
42. Boiler horsepower (mean of test)....	1,576	1,258.4
43. Boiler horsepower (max. hr.).....	1,576	
44. Per cent rating (mean of test).....	252	205.2
45. Sq. ft. water h. s. per b. hp. developed (mean of test).....	3.97	4.88
46. Water evaporated actual per lb., coal as fired.....lb..	5.76	6.27
47. Water evaporated actual per lb., dry coal.....lb..	6.45	7.443
48. Water evaporated f. & a. 212 deg. per lb., coal as fired.....lb..	7.35	7.094
49. Water evaporated f. & a. 212 deg. per lb., dry coal.....lb..	8.35	8.424
50. Water evaporated f. & a. 212 deg. lb. combustible burned....lb..		12.434
51. Water evaporated f. & a. 212 deg. per sq. ft. h. s. per hr.lb..	8.68	5.92
74. Combined efficiency, per cent.....	72.5	69.02

Picking out the items which differ materially and have an influence on operating results, yet do not enter into the calculation of efficiency or capacity, the following table is made:

Hours run	1	4
Ratio grate surface to heating surface...	66.7	67.4
Draft suction over fire.....	.05	.056
Pressure in tuyere box.....	4.1	3.31
Flue temperature	540	457.06
CO_2	15.5	14.19
Coal burned per sq. ft. grate surface per hour	78.5	67.2
Per cent rated horsepower.....	252	205.2

Thus only eight items are selected for direct comparison, and these can readily be taken up in detail.

In a test for capacity, the length of the test has a great influence on the average combined efficiency, as the forcing of a furnace soon results in ash accumulation with resultant clinker difficulties beyond, perhaps, the ability of the furnace to take care of them. So, in these two instances, the short test shows higher efficiency, as would naturally be expected; yet, as there has never been a definite correction factor developed for this discrepancy in test condition, judgment alone must guide in placing its importance.

The ratio of grate surface to heating surface is so nearly alike in the two cases that its influence in this case can be neglected and although the lower the ratio, the greater the capacity that could be expected, the reverse is apparently the case here.

Comparison of the draft conditions readily shows why the first test resulted in higher capacity. With greater forced draft pressure, the loss through the setting would naturally be greater, as more gases are handled, so

it is natural to expect the relations found here: that is, 0.05 in. water over the fire in the first test and 0.056 in the second where the forced draft is only 3.31 in. of water.

Comparison of flue gas temperatures is not quite what should be expected when comparison is made of the temperature of the steam. Thus, in the case of the steam, the difference is 68.94 deg., while with the flue gas temperatures it is 29.7 deg., the advantage being in favor of the first test, which is probably one cause for the higher efficiency.

The item of per cent CO_2 again shows in favor of the first test, since, by reference to a chart in the back

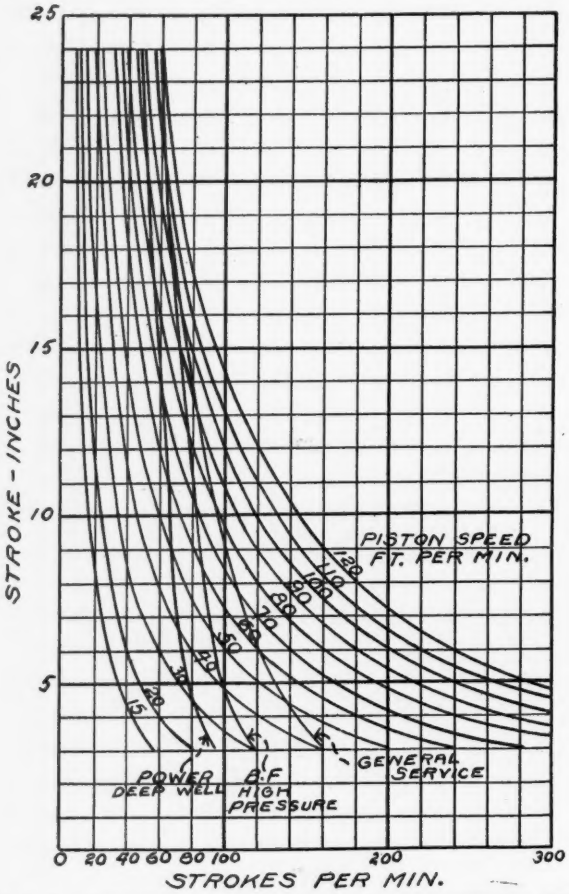


FIG. 1. RELATION BETWEEN PISTON SPEED STROKES PER MINUTE AND LENGTH OF STROKE OF PUMPS, WITH INDICATION OF COMMON PRACTICE FOR DIFFERENT KINDS OF PUMPS.

of the issue, it will be noted that with 14.2 per cent CO_2 the preventable loss in fuel is about 1 per cent, while with 15.5 per cent CO_2 the practical limit of economy in this direction has been reached.

The amount of coal burned per square foot of grate surface per hour shows a difference of 11.3 lb.; the ratio, however, is about what should be expected when considering the next item, the per cent of rated horsepower developed. The efficiencies, however, are just the reverse of what might be expected judging from the load only.

Having made this comparison, the problem is to point out what conditions could be changed in regard to the second installation to bring its efficiency up to that of the first installation. A review of these comparisons indicates that the only conditions which might be bettered are those of CO_2 per cent and flue gas temperature, yet there is no way of knowing that the efficiency of the first installation would have held up had it been of the same duration. The comparison, however, is of advantage, as it points to conditions where improvements can be made.

Pumps

In the testing of pumps, there are not so many variables as in a boiler test and the conditions can in most cases be put on a comparable basis by a simple factor of correction; consideration, however, must be given to the length of the stroke, the strokes per minute, the temperature of the water pumped and the character of the discharge main, as each one of these items has an effect on efficiency for which a standard correction has not been adopted.

The length of stroke and strokes per minute go together to make up the piston speed, which, up to a certain point, has little effect on efficiency; but when that critical speed is reached, the water does not follow up the piston as it should, and the volumetric efficiency drops indefinitely. The usual practice with different kinds of pumps is indicated by the curves, Fig. 1; these speeds are well below the critical speeds so are safe to refer to in analyzing test data.

While the temperature of the water, as far as its weight is concerned, can be and is corrected for, when the efficiency calculations are made as outlined on page 23, a critical point is reached when the vacuum in the suction pipe causes vaporization. The water may be so close in temperature to the boiling point that the difference in the tension of the springs may cause faulty operation in one case, while in the other, with perhaps a slightly lower piston speed, good results are secured. This will be appreciated when reference is made to Tables I and II, which should be compared with test conditions when analysis is being made.

Hydraulic efficiency is a measure to some extent of the character of the piping; but if comparison is made between two pumps working on different pipe lines or two tests of the same pump with different pipe connections, these connections must be considered and the difference in their resistance to water flow corrected before a just comparison can be made.

Feed-Water Heater

As ordinarily installed in a power plant, the feed-water heater is a heat-saving device using exhaust steam for raising the temperature of the water going to the boiler. So if it delivers the water at a temperature as high as can be handled by the pumps, it will seldom be the subject of a test. Where exhaust steam is in demand, however, a comparison of the performance of a heater at various times is advisable and the summary on page 24 will be an aid. This is not a method of figuring efficiency as ordinarily done on the output-input basis, but merely a comparison of items relating to the performance; thus, in analyzing this test, each individual item should be compared with the result in the other test, particular attention being paid first to the temperature difference between the inlet steam and the outlet water; as this is a measure of the results, the smaller this difference the

better. Next in importance comes the transfer of heat to the water per hour as the boiler is relieved of just that much work. Then if some means is available for measuring the amount of condensate in the heater, the heat given up by the steam per hour can be determined and this should be compared with the heat transferred to the water—the difference is lost heat.

The capacity of a heater is proportionate to its size or heating surface; if the temperature difference between inlet steam and outlet water is great, either the heater is overloaded or, in the case of a closed heater, the tubes are dirty; open heaters that have become fouled with scale will, when in bad condition, reduce the heating volume and cause this same result.

Economizer

One of the most important factors which enter into a computation of economizer effectiveness is the weight of the gaseous products of combustion which give a part of their heat to raise the temperature of the water in the economizer tubes. As shown on page 25, the weight of the flue gas is given by the formula

TABLE I. VARIATION OF CALCULATED AND PRACTICAL SUCTION LIFT WITH WATER TEMPERATURE

Vacuum Ref. to 30" Barom., In.	Abs. Press. in Suc'n. Pipe, Lb. Sq. In.	Calculated Lift, Ft. Hd.	Practical Lift, Ft. Hd.	Max. Temp. of Suc'n. Water, Deg. F.	Practical Temp. of Suction, Deg. F.
1	14.21	1.13	0.8	210	156
2	13.72	2.26	1.6	208	152
3	13.23	3.40	2.4	207	148
4	12.74	4.53	3.2	205	143
5	12.25	5.66	4.0	203	140
6	11.76	6.80	4.8	201	137
7	11.27	7.93	5.6	199	132
8	10.78	9.07	6.4	197	129
9	10.29	10.20	7.2	196	124
10	9.80	11.32	8.0	192	122
11	9.31	12.44	8.8	190	118
12	8.82	13.58	9.6	187	115
13	8.33	14.71	10.4	185	111
14	7.84	15.85	11.2	182	108
15	7.35	16.98	12.0	179	104
16	6.86	18.11	12.8	176	100
17	6.37	19.24	13.6	173	97
18	5.88	20.36	14.4	169	94
19	5.39	21.49	15.2	165	90
20	4.90	22.63	16.0	161	87
21	4.41	23.76	16.8	157	83
22	3.92	24.87	17.6	152	79
23	3.43	26.00	18.4	147	77
24	2.94	27.10	19.2	141	73
25	2.45	28.25	20.0	134	69
26	1.96	29.40	20.8	125	67
27	1.47	30.54	21.6	115	63
28	0.98	31.68	22.4	101	57
29	0.49	32.82	23.2	79	53
30	0.00	33.95	24.1		

$$W = 3.036P \frac{N_2}{CO_2 + CO} + (1 - A)$$

Where W = pounds of flue gas per pound of coal
P = carbon burned, stated as a decimal fraction of the weight of coal and is the proportion of carbon in the coal minus that in ash.
N_2, CO_2 and CO are proportions by volume of the gases in the flue gas; and
A = decimal part by weight of non-volatile residue per pound of coal.

To illustrate the use of this formula, a problem will be worked out in which it is assumed that it is required to find the total weight of flue gas per pound of coal burned. As set out in the above formula, the gases will be composed of the air burned, plus the gases into which the mass of coal resolves itself.

A certain Tennessee coal with ultimate analysis as shown by the Government bulletin will be used for the purpose of the problem. Its chemical components are as follows:

Carbon	84.14 per cent
Hydrogen	4.75 per cent
Oxygen	4.37 per cent
Sulphur	1.40 per cent
Nitrogen	1.88 per cent
Ash	3.46 per cent
Total	100.00 per cent

The heat units per pound of coal are 15,262 B.t.u. Analysis of the flue gas shows the following:

Nitrogen (N_2)	88.5 per cent
Carbon dioxide (CO_2)	11.0 per cent
Oxygen (O_2)	0.3 per cent
Carbon monoxide (CO)	0.2 per cent
Total	100 per cent

In correcting for the unburned carbon in the ash pit, assume that 5 per cent of the coal went into the ash pit and that 20 per cent of this was carbon; the deduction for carbon in ash as a fraction of the total coal = $0.05 \times 0.20 = 0.01 = 1.00$ per cent. Therefore value of $P = 84.14 - 1.0 = 83.14$.

TABLE II. NECESSARY INLET HEADS FOR WATER OVER 160 DEG. F. IN TEMPERATURE

Temp. of Inlet Water Deg. F.	165	170	175	180	185	190	195	200	205	210
Practical Suction Pressure Head Ft	1.6	2.7	3.8	5	6	7	8	9.2	10 5	11.5

By substitution in the formula,

$$\text{Lb. air per lb. coal} = 3.036 \times 0.8314 \frac{0.885}{0.112} = 19.93$$

But, in addition, each pound of coal in burning evolves a certain amount of gas; the fuel analysis shows only 0.03 lb. residue, representing "A" in the formula, and comprising the non-volatile products of combustion. Therefore the gas evolved $(1 - A) = 0.97$ lb.

Therefore, W, total weight of gas per pound of coal = $19.93 + 0.97 = 20.90$ lb.

The economizer comes in the class with the exhaust steam feed-water heater in that it is a saver of heat, and the limit to the amount of heat that can be taken from the gases is governed more by the requirements for draft in the furnace than by the efficiency of the economizer. Obviously, by installing sufficient heating surface in the economizer the temperature of the gases can be reduced so low that no natural draft will be produced, so the object of an economizer test is usually to ascertain whether or not the economizer installed is maintaining its original heat transmitting qualities. For this reason, the tests suggested on pages 24 and 25 are designed to give the heat absorbing ratio; that is, the total heat gained by the water divided by the total heat of the inlet gases above the temperature of the inlet water.

The test is rather complicated in that it requires a complete analysis of the coal and also of the flue gases; the use of these items is shown in the problem worked out above and the other necessary steps are given in the summary on page 26. For any particular economizer

installation this test will show by the absorption ratio the relative operating conditions of the equipment and the preventable losses being due to the accumulation of soot and scale, and the radiation of heat from the exposed surfaces are readily traced to their sources.

Steam Engine Tests

The procedure for comparing engine tests is very much the same as has already been described for comparison of boiler tests; that is, setting the items of the summary in two parallel columns, picking out the results and conditions where discrepancies of consequence are noted and analyzing these for their effects on the efficiency.

The percentage of rated capacity at which the test is conducted has a considerable effect on the efficiency shown by the test. Although manufacturers strive to produce engines that have straight steam consumption lines, there is always more or less of a hump in the efficiency curve at the rated capacity of the engine; therefore, consideration of this fact should be taken into account when comparing tests.

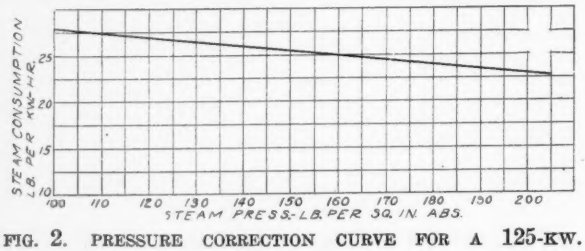


FIG. 2. PRESSURE CORRECTION CURVE FOR A 125-KW. STEAM TURBINE

It would be unjust to judge two types of engines by tests made on units of different sizes, as a unit of a larger size of any type of engine is likely to show a higher efficiency than one of smaller size. No general method of correcting for this difference in size is possible, as engines of different types do not have the same variation in efficiency with size.

In compound engines, the effect of the receiver pressure on the efficiency is not generally appreciated, nor has there been developed a method for obtaining a factor of correction to care for differences, so this point should be noted.

Steam pressure in the jackets and reheater has a considerable effect on the initial condensation of an engine, thus naturally affecting the efficiency yet not entering into the calculation.

Other things being equal, engines run at the greater number of revolutions per minute will show a lower efficiency than the slower speed engine, even though the piston speed in feet may be the same. This is, in a measure, due to the fact that with high-speed engines it is necessary to provide greater clearance, which is detrimental to efficiency.

No engine test of any value can be made without indicator diagrams and in the comparison of tests of one engine with another or of tests of the same engine, the diagrams should be compared most carefully, for by them the defects of adjustments can be seen more surely than by any other means.

The methods of making corrections for vacuum, superheat and steam pressure will be taken up in connection with steam turbines. These conditions have different effects upon different types of units, so it is necessary to secure from the manufacturer the correction curves applying to the type of engine tested.

Steam Turbines

When contemplating a change from one type of unit to another, as from engine to turbine, it is necessary to work from a common basis; therefore, in the summary of the turbine test given on pages 29 and 30, the net work per B.t.u. consumed by the turbine is comparable with a like item resulting from a test of an engine. In such cases, however, the surrounding conditions are usually changed somewhat so that the over-all results affect not only the prime mover, but also the boilers. So comparisons such as mentioned above should not be confined to engine and turbine, but include practically the whole plant.

Comparisons of tests of turbines can be made similarly to those of engines. Besides careful comparison between efficiency and economic results, several conditions which do not enter into the calculations should be noted. As with engines, the percentage of the rated capacity of the turbine at which the test is conducted will affect the efficiency and can be corrected for only by reference to an efficiency load curve of the turbine or one of identical design and capacity.

Steam pressure at the throttle has an effect on pounds steam consumption almost in direct proportion to difference in pressures in pounds absolute, as will be seen by reference to Fig. 2, which is a manufacturer's correction chart and is therefore for a specific type of turbine.

The barometric pressure will affect the results of the condenser and in turn, the pressure in the exhaust pipe of the turbine, so these items need comparison and the results of different tests may be corrected to the same vacuum by referring to chart similar to Fig. 3, which is for a 125-kw. turbine and is applicable only to this size and individual type and is not for general use.

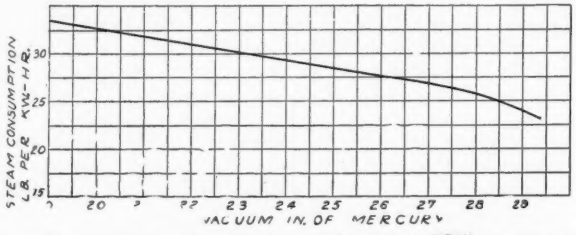


FIG. 3. VACUUM CORRECTION CURVE FOR A 125-KW. STEAM TURBINE

Again, a correction for superheat should be made in a similar manner to that employed for steam pressure and vacuum by reference to a curve similar to Fig. 4.

In using these curves, the method employed is to add to or subtract from, as the case may be, the steam consumption per kw.-hr., the difference indicated by the charts for the changed conditions. This method, which is recommended by Moyer, is applicable to engines as well as turbines; but each type and size of unit must have curves of its own worked out from numerous tests and although drawn for corrections at full load, they will apply without appreciable error at loads ranging from 50 to 150 per cent rated load.

Surface Condensers

To get the greatest value from the results of condenser tests, comparisons should be followed out along the general lines suggested for other equipment. The basis of comparison is the heat transmitted per square foot of surface per degree difference per hour, as indicated on the summary sheet, page 30. Comparison of this item as calculated at different times from tests will show the relative working effectiveness of the condenser, thus giving an indication of the condition of the tubes.

The object of the condenser is to create vacuum, so this item is of prime importance, yet does not enter into the calculation of the coefficient of heat transmission, but should not be overlooked in the comparison.

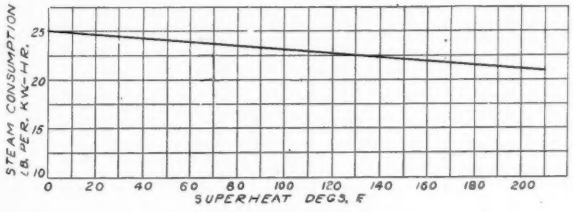


FIG. 4. SUPERHEAT CORRECTION CURVE FOR A 125-KW. STEAM TURBINE

Temperature of the cooling water is the most important variable condition limiting the effectiveness of the condenser, yet changes in this temperature can be counteracted by changing the amount of water used. The inter-relation of these two items at various times is enlightening, and analyses of tests should include comparisons of them.

Generators and Motors

Tests of generators and motors in power plants for efficiency are purely input-output tests and ordinary surrounding conditions other than those which enter into the efficiency calculations have but little effect upon the efficiency results. The duration of the tests, however, should be noted when comparisons are being made, as the rise in temperature of the coils causes a falling off in efficiency, so a gradually decreasing efficiency is obtained until the temperatures become constant, when the efficiency remains constant for the load being carried.

In the operation of motors and generators, more or less dirt accumulates on the armature and field coils, thus preventing the radiation necessary to keep the temperature down to an efficient point. This increased temperature causes greater resistances in both armature and field coils, resulting in lower efficiencies at the same loads. Rise in atmospheric temperature or the temperature of the cooling air passed through the generator also, for the same reasons, causes a falling off in efficiency, and note of these conditions should be made when tests are being compared.

Air Compressors

The same general scheme for analyzing air compressor tests may be used that has been described for other apparatus. As many variables affecting the efficiency are met in conducting a test of air compressors, it is difficult to determine just what condition is causing a reduction in efficiency, yet a few of these items should be noted and corrections made where possible.

When compressors of different sizes are being compared, the one with the larger dimensions may be expected to give higher efficiency. As with pumps, the connections, both suction and delivery, will have an effect on the amount of compressed air delivered, as pipes of smaller size have more friction and thus cause a lower pressure to the suction valves and a higher pressure at the delivery end.

Comparison of the indicator diagrams will indicate leaking suction and discharge valves, and clogged piping.

The analysis of a well conducted test of any piece of power plant equipment is of value in pointing to conditions that can be bettered, and the whole test is of no value unless the information given by the analysis is put into use.

Analysis of Operating Records

Methods and Means for Finding Preventable Losses

IN THE operation of a power plant certain conditions are given, others are controlled by the operatives. If the given conditions were always the same the problem would be simple and, once solved, there would be little need for an extensive record system; but these conditions are changing continuously, so that the task of maintaining controllable conditions correct for each change in noncontrollable conditions is continuous and endless, as long as the plant is in operation. The interrelationship of conditions is intimate; the change in one weather condition, for example, may affect the operation of several pieces of apparatus and thus influence the final results to a considerable degree. The human senses alone cannot be relied upon to guide the operative; he must have delicate instruments. Then a change in given conditions calls for a change in controllable conditions if the plant is to be kept at its highest operating efficiency.

Any condition in a power plant may be classified under one of the following general heads: (1) noncontrollable, (2) semicontrollable, and (3) controllable. Under the first heading comes the weather, given equipment, and other things which must be accepted whether desirable or not. The semicontrollable conditions are those which are not absolute, but may be changed somewhat by discrimination in selection or treatment, such as quality of fuel, quality of water, load curve, etc. Controllable conditions are those which the operator has absolutely under his control, such as steam pressure, draft, thickness of fuel bed, division of load among generators, time of blowing down boilers, flue blowing, and the like. With operating records showing these changing conditions, the task of the engineer is to determine what conditions he can change to meet the noncontrollable condition, and then give general instructions to his operating force in order that the highest over-all

efficiency may be obtained. When this has been done the record has served its purpose and any further records are of value only in keeping a check on plant operation and maintaining equipment in best condition.

To analyze the daily record, then, the task is to determine whether or not each equipment unit is working at its highest efficiency, and if not, why not. The more complete the records the easier will be the work and the more certain will be the results.

Starting with the plant as a whole the usual plan is to draw curves, extending them each day, of the principal over-all results and noncontrollable conditions. Thus, in the accompanying illustration, Fig. 1, are shown a number of curves of daily averages and totals. A study of these will show how the outside temperature affected the amount of live steam used for heating purposes, also the influence the power load had on the amount of live steam for heating. The division of coal used for heat and power is also shown.

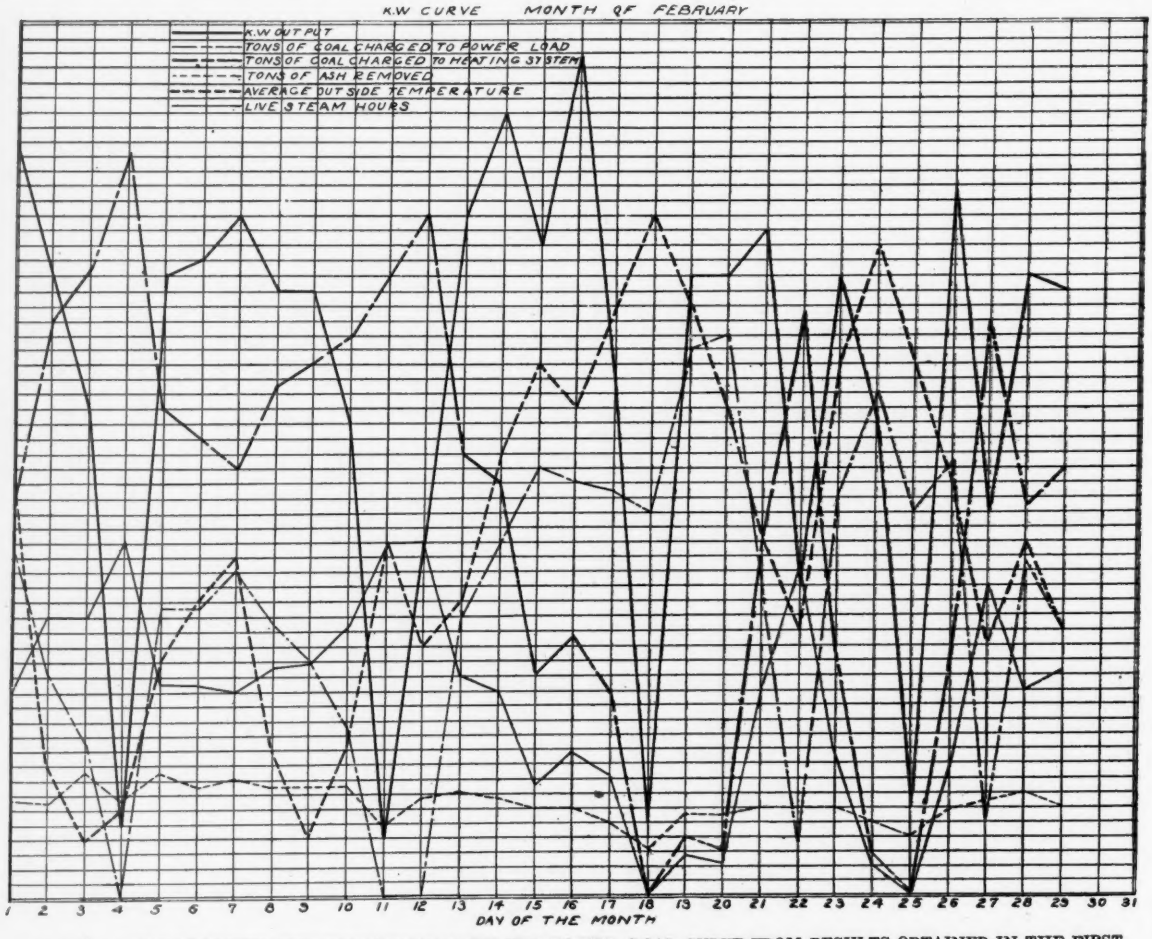

K.W CURVE MONTH OF FEBRUARY
K.W OUTPUT
TONS OF COAL CHARGED TO POWER LOAD
TONS OF COAL CHARGED TO HEATING SYSTEM
TONS OF ASH REMOVED
AVERAGE OUTSIDE TEMPERATURE
LIVE STEAM HOURS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DAY OF THE MONTH

FIG. 1. CURVES PLOTTED FOR COMPARISON WITH THE POWER LOAD CURVE FROM RESULTS OBTAINED IN THE FIRST NATIONAL BANK BUILDING, CHICAGO

In the plant furnishing both power and heat the item which is most sensitive to changes is the pounds of steam generated per pound of coal, while in the plant furnishing electric power only the item of greatest importance is the pounds coal per kilowatt-hour delivered from the switchboard. These curves drawn day after day will be found to vary quite considerably, although the average for corresponding months of different years will generally be nearly equal. Thus the conclusion is drawn that the principal factors affecting the changes are seasonal and the conditions that change with the seasons are weather and load. So temperature, which is the principal item in regard to weather, and load conditions are plotted in comparison with coal per kilowatt-hour and pounds steam per pound coal.

Further study is likely to reveal that for weather and load conditions substantially the same better results are obtained at some times than others. Why this should be, would be purely a guess without adequate records; but with these, several things can be looked for, such as the boilers in service at these times compared with others, the uniformity of the load during the day, the condition of the boilers as regards scale and soot, the men on duty in the boiler room, in fact, practically all items which enter into the efficiency of the various pieces of machinery could be examined until the cause of the improvement is accounted for. Once found, directions to maintain that condition should be given and permanent betterment is secured. Likewise when results fall below what is considered best operation, investigation is called for so that they will not continue. For this reason the daily record has its advantage, for undesirable condi-

tions will be caught early and changed before the loss becomes great.

As will be noted from the foregoing, the drawing of curves is merely the start in the process of analysis. These give merely relative values and unless the records have been kept long enough to establish standards of practice for the plant in question no comparison can be made; once, however, these standards are determined, variation therefrom should be studied with care.

To make this process systematic and of greatest value, a step by step method should be followed out each day which, when once standards are established, will point immediately to the offending machine or condition. As a guide, an outline such as that shown in Fig. 2, for the plant which is being considered, could be made. Taking up this outline item by item, the method of analysis of a daily record will plainly be seen and with the aid of the charts and tables in the back part of the issue, together with data from tests of equipment in the individual plant, the work can be done rapidly and with certainty that the condition causing the disturbance will be found.

Three curves will be drawn and kept up to date every day; these are: pounds steam generated per pound coal, pounds coal per kilowatt-hour delivered at the switchboard and pounds of live steam used for heating. These are found from steam and wattmeters in the plant. To these could well be added power load curve and another for the outside temperature.

As soon as possible establish a standard evaporation ratio, say 9 lb. steam per pound coal. This can be done by reference to tests of the boiler room run under direct supervision of the engineer. Where power only is delivered by the plant, the pounds coal per kilowatt-hour can readily be established by testing the generating unit or units as a whole; but when live steam is used for heating, the inter-relationship of the power and heating loads makes the problem more difficult and only by observation over several months or years can a definite standard for heat required with different temperatures and power loads be established. With these established for the plant, any discrepancy in any one of the three main items will be apparent when the power load and the outside temperature are taken into consideration. To make this comparison rapid, a table, shown here in blank form, should be made up from records and kept handy for reference. This table will need revision as the plant improves in efficiency or changes in equipment are made; but even if not up to the best the plant can do, it will be a great aid to the man in charge.

From these five items recorded in the daily log there will be one or more of the three semicontrollable items which may call for further investigation. Pounds of steam per pound of coal is influenced by several items, the most important of which will be found in the simplest daily record sheet shown in the article on Planning Operating Log Sheets as Fig. 14.

Steam pressure is established by the design of the boiler and should be kept constant, for a drop in pressure calls for higher evaporation and more steam, since the engine economy is less with reduced pressure.

Load on the boilers is not under the control of the engineer, although he can regulate to some extent the distribution throughout the day by varying the program of his power using equipment which does not require constant operation, such as coal and ash handling equipment, house pumps in connection with storage tanks, cool water system where storage capacity is provided and other equipment special to the plant. This item should be compared with the ratings of the boilers in service to see that they are, on the average, working at as nearly their points of maximum efficiency as the load conditions will permit. Higher combined efficiency is usually obtained by overloading a boiler than underloading it; so in arranging the program of operation, higher economy will be obtained by working the boilers to the limit on peak loads, while at low load periods they work around the normal rating, than by putting more boilers in service in order to keep the load on each more nearly the rating. The form shown as Fig. 14 in the article on Planning Operating Log Sheets is not sufficient to permit a detailed study of this item; the forms, Fig. 15 to 16a, will give the necessary information or form Fig. 14, together with personal observation may suffice.

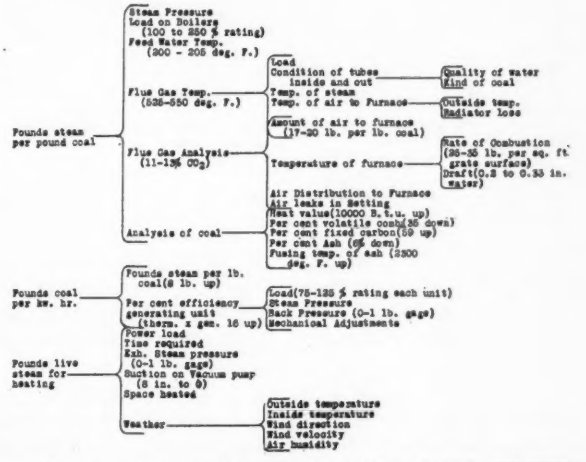

Steam Pressure
Load on Boilers (100 to 250 % rating)
Feed Water Temp. (200 - 205 deg. F.)
Load
Condition of tubes inside and out
Quality of water
Kind of coal
Flue Gas Temp. (525-550 deg. F.)
Temp. of steam
Temp. of air to Furnace
Outside temp.
Radiator loss
Pounds steam per pound coal
Amount of air to furnace (17-20 lb. per lb. coal)
Rate of Combustion (25-35 lb. per sq. ft. grate surface)
Draft (0.2 to 0.35 in. water)
Flue Gas Analysis (11-13% CO2)
Temperature of furnace
Air Distribution to Furnace
Air leaks in Setting
Heat value (10000 B.t.u. up)
Per cent volatile comb (25 down)
Per cent fixed carbon (50 up)
Per cent Ash (6% down)
Fusing temp. of ash (2300 deg. F. up)
Analysis of coal
Pounds steam per lb. coal (8 lb. up)
Pounds coal per kw. hr.
Per cent efficiency generating unit (therm. x gen. 16 up)
Load (75-125 % rating each unit)
Steam Pressure
Back Pressure (0-1 lb. gage)
Mechanical Adjustments
Power load
Time required
Exh. Steam pressure (0-1 lb. gage)
Pounds live steam for heating
Suction on Vacuum pump (6 in. to 0)
Space heated
Outside temperature
Inside temperature
Wind direction
Wind velocity
Air humidity
Weather

FIG. 2. OUTLINE FOR ANALYZING DAILY RECORDS SHOWING SUGGESTED STANDARDS

Temperature of feed water may vary 10 to 15 deg. if the rate of feeding is not watched carefully; establish a standard temperature and examine the daily records to see that the variation is within definite limits, say 5 deg.

Flue gas temperature is an indication of the amount of heat that is going up the stack. Boiler tests at various loads will determine what it should be for the individual plant and frequent reference to the chart showing loss due to flue gas temperature in the back of this issue will serve as a reminder that this should be low. It will be noted in the outline that several conditions affect this temperature. Increased load calls for the handling of more gases, which requires higher temperature. The condition of the tubes as to scale and soot affects the heat transmitting ability of the metal, consequently dirty heating surfaces mean higher flue temperature for the same load. The attendants can control this condition by systematic cleaning and tube dusting; but if the temperature is habitually higher than it should be for the conditions, a study of the quality of water and the kind of coal will not come amiss.

Temperature of the steam is established by the design of the boiler for the pressure to be carried, so is a fixed

figure and it represents the theoretical minimum temperature of flue gas and should be noted in case an investigation of flue gas temperature is made.

Naturally, the lower the temperature of the air to the furnace, other things being equal, the lower will be the flue gas temperature. As this air comes from outdoors through the boiler room, its temperature will depend upon outside temperature and heat radiated from hot surfaces in the plant.

The amount of air carried into the furnace influences the temperature of gases proportionately, the rate of combustion remaining the same, but frequently leakage through the setting causes the overloading of the gases with air with a proportionate decrease in temperature. From the foregoing, it will be noted that flue gas temperature may be caused by one undesirable condition to be too high, yet by another undesirable condition to be too low; so that the two coming together may give a reasonable temperature, yet poor results. The next

Corrected Outside Temp. deg.	Power Load Kw. hr. per day								
	Minimum to						maximum		
	st. per lb. coal	coal per kw. hr.	lb. live steam	st. per lb. coal	coal per kw. hr.	lb. live steam	st. per lb. coal	coal per kw. hr.	lb. live steam
-20									
-10									
-5									
0									
5									
10									
90									
100									

FIG. 3. BLANK FORM TO BE USED IN SHOWING RELATION BETWEEN OUTSIDE TEMPERATURE AND LOAD CONDITIONS

item, however, flue gas analysis, the most important determination being the percentage of CO_2, will show up excess air, so these two items must be considered together and their inter-relationship is shown in a table at the back of the issue.

Ordinarily 12 per cent CO_2 in the flue gases is considered good, yet many plants maintain 15 per cent while others, due to individual furnace construction, find that the highest combined efficiency is obtained when 10 per cent is maintained. Tests only will determine this point. A standard, however, should be established and variations therefrom should be sufficient cause for investigation. The points to be looked into are the amount of air to the furnace, temperature of the furnace which depends upon the rate of combustion and the draft, air distribution to the furnace, i. e. whether or not the proper proportion is going over the fuel bed, and examination for air leaks in the setting.

Next on the list of items affecting the ratio of evaporation is the analysis of coal which would include the heat value, per cent volatile combustible, per cent fixed carbon and per cent ash. Whenever a change of fuel is made, this should be looked after carefully, for the furnace must be properly designed to suit the fuel or the results will not be satisfactory. High volatile coals require greater furnace volume and more air over the fuel bed, while coals high in ash become a burden on the grate and are likely to cause clinker if the temperature runs high.

Power Generation

In the outline are noted two general items which affect the pounds of coal per kilowatt-hour of power generated; these are, pounds of steam per pound of coal and per cent efficiency of the generating units. The first item has already been discussed, so the second will be analyzed. Engine-generator efficiency is influenced by the per cent of rated load carried; the variation in efficiency due to this cause can readily be seen by reference to the characteristics of the generator installed and it should be appreciated that for each per cent increase in engine generator efficiency where power alone is being developed, nearly one per cent is saved in coal.

Steam pressure also has considerable influence on the efficiency of the unit, as will be noted in Fig. 4; a drop from 150 to 125 lb. in steam pressure results in a reduction of one per cent in thermal efficiency of a noncondensing engine or in round numbers, 7 per cent increase in steam consumption, with a condensing engine the same drop results in an increase of approximately 4 per cent. Even a 10-lb. drop will result in an appreciable loss of approximately 2.8 and 1.6 per cent respectively of the steam used for power generation.

Effects of variations in back pressure are more serious than equal changes in steam pressure as will be noted in Fig. 5 so the need of keeping these pressures proper for the design of the plant can well be appreciated. Both of these pressures are, within limits, under the control of the operatives; so wide variations should not be tolerated, as they can readily bring the steam consumption above necessary requirements.

The mechanical adjustments of the engine are cause for a great deal of waste of steam, particularly when the exhaust goes to atmosphere or to a condenser. For detecting these, the steam engine indicator is the most reliable instrument and its frequent use will point to

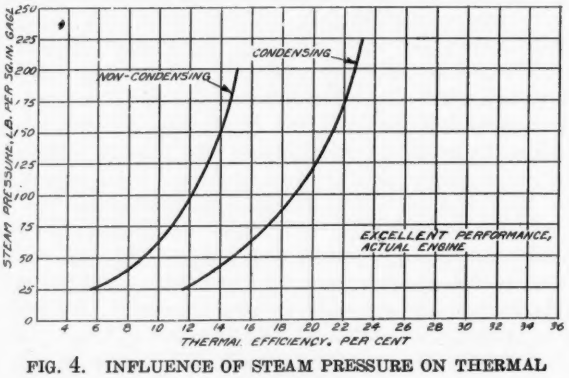


FIG. 4. INFLUENCE OF STEAM PRESSURE ON THERMAL EFFICIENCY

valve leaks, slipped eccentric and other defects of valve setting before the trouble has caused the waste of steam a great length of time. Excessive friction, poor alinement, and other mechanical defects will make themselves known by hot bearings, knocking and groaning so that they usually demand attention immediately and are not difficult to locate.

If the plant is equipped with some means for measuring or even estimating the amount of steam used by the separate units, it will not take long to establish a standard of steam consumption per kilowatt-hour developed to be used as a daily check on operation.

Heating System

Considering now the items which affect the number of pounds of live stem used for heating purposes, the

first one given is the power load. Without any power load, heating would necessarily have to be done entirely with live steam; as the load increases, more exhaust steam is available and less live steam will be used unless temperature conditions change. Thus many office buildings are heated by live steam during the night; but in the daytime when the power load runs up, sufficient exhaust steam is available to maintain proper temperature conditions. This power load is not under the control of the engineer, therefore it must be accepted as it

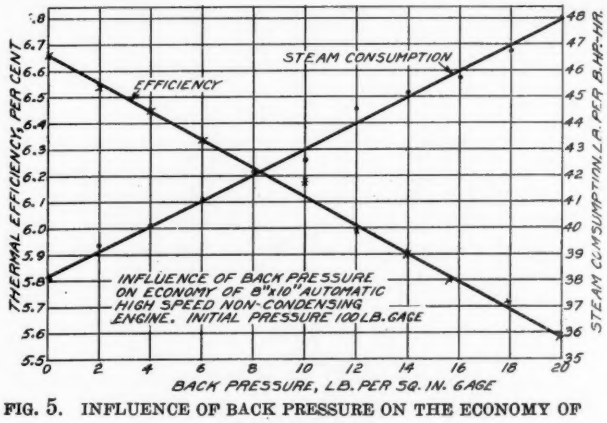

THERMAL EFFICIENCY, PER CENT
STEAM CONSUMPTION, LB. PER B.HP.-HR.
STEAM CONSUMPTION
EFFICIENCY
INFLUENCE OF BACK PRESSURE ON ECONOMY OF 8"x10" AUTOMATIC HIGH SPEED NON-CONDENSING ENGINE. INITIAL PRESSURE 100 LB. GAGE
BACK PRESSURE, LB. PER SQ. IN. GAGE

FIG. 5. INFLUENCE OF BACK PRESSURE ON THE ECONOMY OF A STEAM ENGINE

comes; but its influence should be noted each day for unusual conditions.

The time during which the live steam is turned on influences almost in direct proportion the amount of steam used, so this item is of principal importance. When checked against the power load, it will be noted that power and live steam for heat alternate with some overlapping during cold weather. Careful comparisons will enable the engineer to predict his live steam heat requirements from weather and load conditions, this being the case he can give definite directions to turn on or off live steam when certain temperature and power

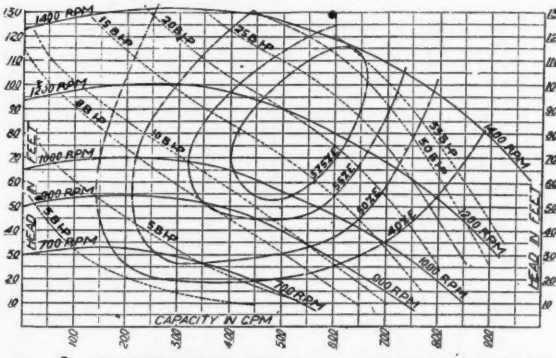


FIG. 6. ISOEFFICIENCY CURVE OF A CENTRIFUGAL PUMP

load conditions are reached. These must be established for each individual plant.

As the heat in steam depends upon the pressure, the amount of steam required to heat a building also depends upon the pressure at which it is delivered. Increasing the back pressure decreases the efficiency of the engine also decreases the amount of live steam required for heating, so a definite standard should be decided upon and this maintained with but little variation. Another principle of heating with exhaust steam is that by lowering suction pressure on the vacuum pumps more heat can be radiated from the return water. The reason for this is shown by saturated steam tables where a drop of one pound absolute in the steam pressure indicates a lower heat content of the liquid of approximately 3½ B.t.u. per pound. Here again standard practice should be well defined.

It is not uncommon that the amount of space requiring heat will vary from time to time and if an accurate check on the heating system is desired, a record of the space heated should be kept for comparison.

Above all other conditions, that of the weather is the most influential in determining the amount of live steam required and it will affect no two buildings alike, so here is a place where individual investigation is required. Outside and inside temperatures, wind direction and velocity and the percentage of humidity each has

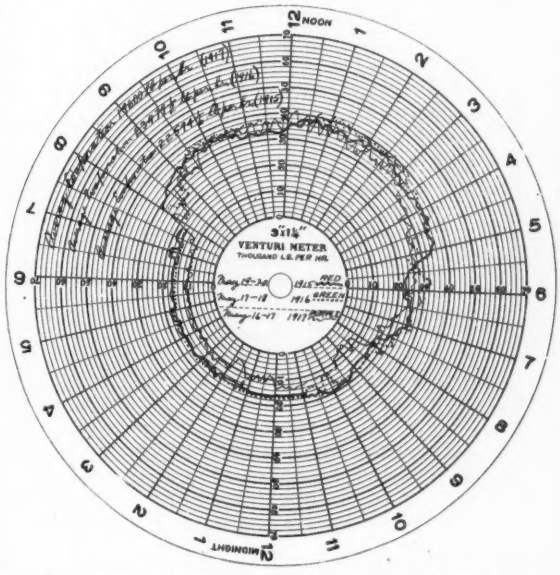


FIG. 7. COMPARISON OF FEED WATER FLOW ON THREE DAYS ONE YEAR APART

its influence on heat requirements and with study and comparison a correction factor for temperature can be worked out for the different wind directions and velocities, also humidity. For practical purposes, the inside temperature may be considered constant, as it should be, which will reduce the problems.

Using Daily Records

It would be manifestly impracticable for the average chief engineer to investigate every item in his record every day, therefore the following plan is suggested, which will make the work comparatively rapid yet give the engineer full use of the records.

It is not sufficient that the economy of the plant remain constant; it should increase, so when standards are set up they should not only be maintained but improved and the road to improvement is by studying details separately, making slight changes and watching results. If improvement is made, the change could be increased until a decline is noted; the maximum point then is established as the correct condition to maintain.

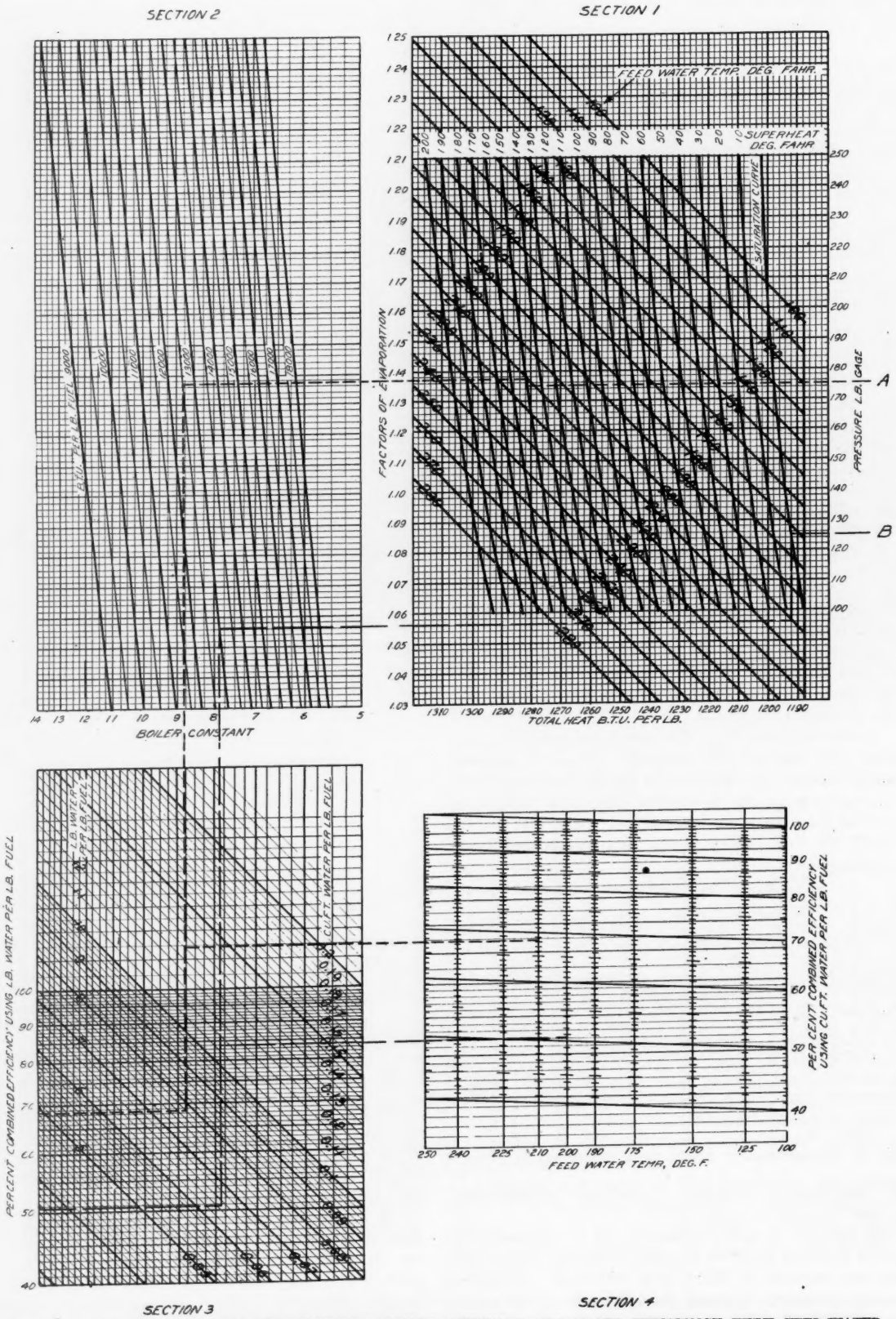


FIG. 8. CHART FOR FINDING THE COMBINED BOILER, FURNACE AND GRATE EFFICIENCY WITH FEED-WATER MEASURED IN POUNDS OR CUBIC FEET

So each day the outline given should be followed while examining the daily record and compared with the standards which have been established. A substantial variation above or below the established standard in any one of the three main items will point toward the detailed items to be examined. If above the standard, there is an apparent improvement and if the condition causing that improvement is controllable or semicontrollable, there is a chance to make that condition permanent in the operation of the plant with beneficial results. On the other hand, if the standard has not been reached the detailed items which affect the over-all result are examined and compared with their standards until the offending item or items have been found and proper instructions given or changes made to remedy the trouble.

The time required to compare operating records with the main items and their standards, then to follow the unsatisfactory item into its subdivisions and make comparisons here with standards and again go into the details would take but a few minutes of the engineer's time and with properly kept records and instruments, the plant would be kept up to its highest efficiency at all times.

Power and Steam Using Equipment

So far, consideration has been given only to the power and steam generation of the plant. This, however, is only part of the problem of record analysis, as much of the machinery about the plant is driven by steam or electric power and these uses should be made as economical as possible. So for each pump, engine,

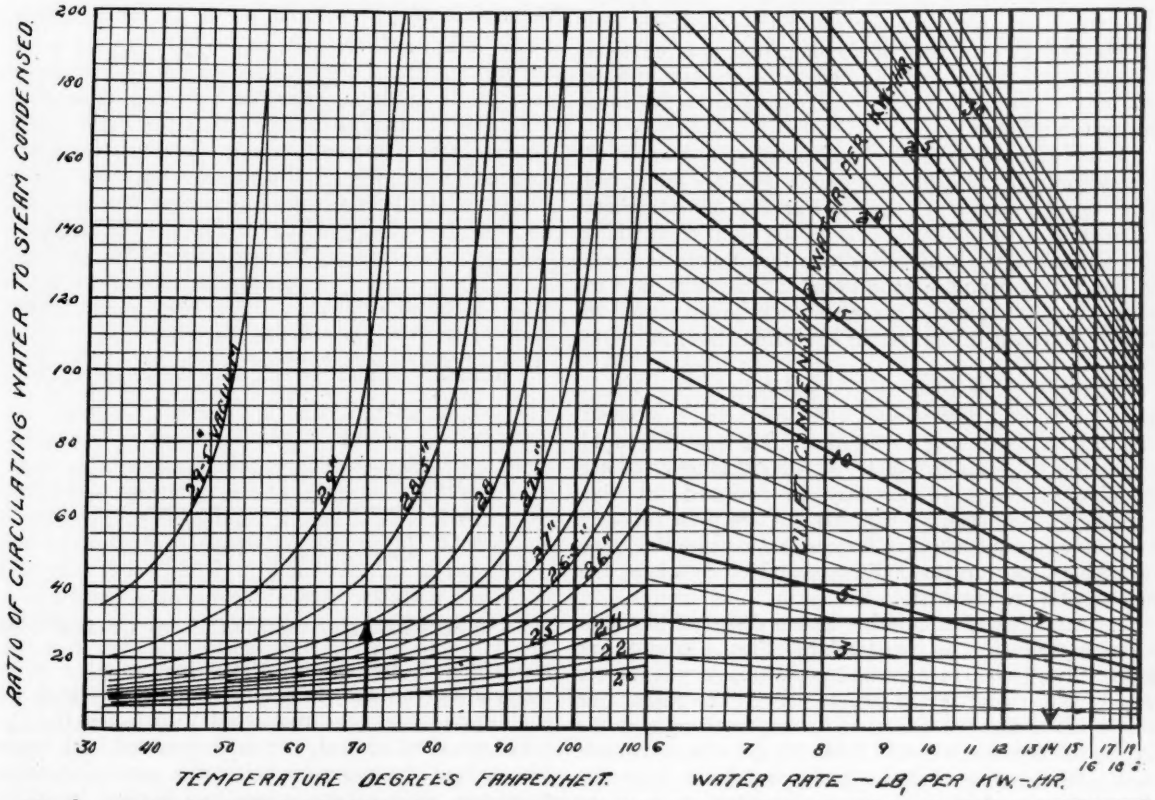


FIG. 9. CHART FOR THE DETERMINATION OF THE WATER RATE OF A TURBINE WHEN THE INITIAL TEMPERATURE OF THE CIRCULATING WATER, THE DEGREE OF VACUUM, AND THE CIRCULATING WATER PER KILOWATT-HOUR ARE KNOWN

The big problem in any plant is to establish the original standards and this cannot be done in a day, but will take a year or more of constant observation and even after they have been established, changes in equipment of the plant will indicate changes in operating conditions that should be made; so the process is continuous, but the basic principles can be observed.

To aid in establishing standards and making analysis, the last pages of this issue are devoted to charts and tables dealing entirely with operating conditions; these tables are thoroughly indexed, so that when it is desired to know what effect a change in one condition will have upon other conditions, reference to the index and tables and charts will answer the question.

motor or steam or power using device a standard of service for comparison should be set and followed up carefully day after day.

Such machinery should be run at its highest efficiency wherever possible and only by tests can these conditions be determined. The data collected on the record sheet should be such that it will give an indication of the running efficiency though detailed conditions need not be recorded; but when continued inefficiency is obtained, a special test is in order to determine the cause.

In all the records suggested for auxiliaries and equipment, the time of starting and stopping and the hours in service will be found to occupy a prominent place. It

is upon this and the load carried that the program of operation is based and where the choice of several machines is given, a carefully worked out scheme can be devised to maintain high efficiency by working the machines at as nearly their maximum point of efficiency as possible. Isoefficiency curves such as shown here for a centrifugal pump will aid in this direction.

To reduce the cost of service rendered by a power plant, it is necessary to plan an adequate record, to install the instruments necessary for keeping the record and guiding the operatives, to keep the records up to date, to establish standards of operation, to compare daily operation with these standards, to determine causes for variations, to correct errors in conditions and cause changes in equipment which will increase efficiencies.

Records kept and curves drawn without determining the causes for variations and correcting of faulty conditions which are under the control of the operatives will get nowhere and the time of keeping them is a practical loss; but with the method outlined above, the tax on time is a minimum and the record becomes a positive index to faulty conditions.

With graphic recording instruments, a scheme of comparison employed in some plants is to use the charts three times a year apart, thus in Fig. 7 is shown a chart taken from a feed water meter. In the plant from which this was taken, the load varies with the day of the week, so the charts compare conditions on the same day of weeks one year apart. This scheme will prove an aid in many plants where changes in equipment have not been made.

Among the more recent aids which have been developed for rapidly determining how nearly the equipment in the plant is coming to the theoretical and for rapid calculation of formulas which are somewhat involved are calculating charts. These may be designed to solve almost any mathematical formula but are most valuable where the formula contains factors that require reference to perhaps two or three different tables or where the mathematic are involved.

As examples of calculating charts designed to aid in keeping operation up to standard, Figs. 8 and 9 are given. The boiler, furnace and grate efficiency is seldom worked out except in the largest plant. The reason for this is no doubt because of the work involved and the tax on the engineer's time. With the aid of a chart such as Fig. 8 the time required is only a minute when the steam pressure, feed-water temperature, heat value of the coal and the ratio of evaporation are known.

The chart is based on formula:

$$\text{Per cent combined efficiency} = \frac{F \times w \times 970.4 \times 100}{W \times \text{B.t.u.}}$$

In which F = factor of evaporation
w = weight of water in pounds.
W = weight of coal in pounds.
B.t.u. = heat value of one pound coal.

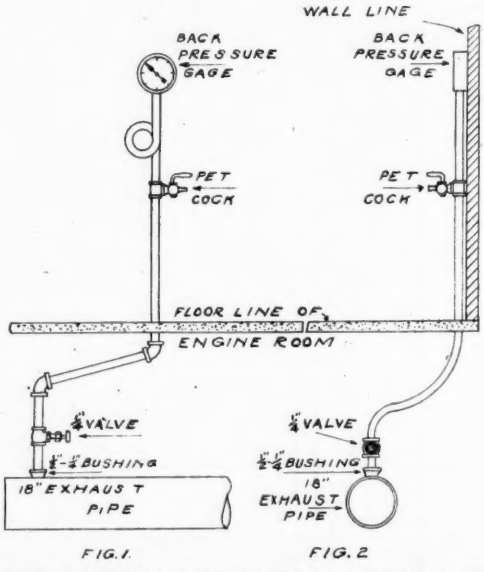
The method of using the chart is shown by the dotted lines starting with A and B.

Figure 9 is convenient for estimating the water rate of a condensing engine or turbine where no steam meter is available for measuring the steam to the unit; it is necessary, however, to know the amount of circulating water used, the kilowatt hours developed, the vacuum carried and the temperature of the circulating water. The heavy lines with arrows show how the chart is used. In the development of this chart it is assumed that the transmission of the heat is perfect, as would be the case with a jet or barometric condenser.

By the use of such aids, the interrelationship of operating data is made known in a way that can be done in almost no other way, certainly not by the working of isolated single problems.

Back Pressure Gage Piping Trouble

THE SKETCHES show how we connected up a back pressure gage to our 18-in. exhaust line and could not get a reading in either position. We first connected it up as shown in Fig. 1. There was a ½-in. coupling welded into the top of the 18-in. exhaust line under the floor of the engine room, which was reduced to ¼ in. To this was connected a short ¼-in. nipple and valve, a 14-in. piece of pipe with ell, a 9-ft. horizontal run with



BACK PRESSURE GAGE CONNECTION TO EXHAUST PIPE

about a 3-in. fall toward the source, another ell and straight up through floor about 6 ft. to the back pressure gage. The gage registered 2 lb. when the ¼-in. valve was first opened, but later dropped back to zero. We opened the pet cock below the gage and nothing came out, while exhaust steam was flowing freely from the exhaust head on the roof. We then took the pipe down to the ¼-in. valve and found it full of water, which led us to believe that water would not run back the 9-ft. horizontal piece. We then connected the gage directly above the outlet in the pipe and carried it back against the wall in 45-deg. bends, as in Fig. 2, and it acted the same as in the first case. The pipe filled with water and would balance the pressure.

It had us puzzled for a while; why a gage would not register through a ¼-in. pipe. We took down the piping again, and that night when we shut down, we took out the ½ by ¼-in. bushing and put in a ½-in. short nipple and valve. We put the ½ by ¼-in. bushing in top of the valve and then connected the ¼-in. pipe to the gage, and it has been registering correctly ever since. This shows it was the ¼-in. valve that was causing all the trouble; the passages were too restricted.

JOHN WILLIAMS.

Improvements and Replacements

When and Why They Should Be Made

THE END and aim of improvements in a power plant are two, namely, to reduce the cost of producing power (and heat ordinarily) and to improve the reliability of service.

It is necessary before considering the purchase of new equipment, that the present plant be brought up to the highest operating efficiency possible by methods such as have already been suggested in these pages.

Throughout the operation of the plant, endeavor has been made to increase the output, decrease the unit costs and maintain steady, reliable service; and it is apparent that the limit in this direction has been reached.

Why Install New Equipment?

New machinery or construction that will reduce present unit costs and improve the quality of service must do so by increased efficiency of operation over that possible with the use of existing equipment.

Increased efficiency of operation will reduce costs by saving in the cost of one or all of the items of fuel, supplies, labor and repairs and renewals. Investments for new equipment will be induced likewise by saving in the fixed charge of amortization for depreciation, insurance, taxes or rent and management.

When improvements will permit us to do the same work at less cost than is possible with existing facilities we say that the latter are obsolete, inadequate or physically run-down.

Obsolescence as has been explained in another section, cannot be predicted and is due to the invention of more efficient machinery. Obsolescence should not be confused with depreciation due to wear and tear. The increased cost of repairs due to long service may cause equipment to depreciate physically to such an extent that it is cheaper to sell it for its salvage value and buy a new machine of the same identical make and kind whose upkeep expense will be such that as compared with the old it will justify the investment of new capital. Such wear and tear, called natural or physical depreciation, can be predicted by past performances, and a depreciation or renewal reserve fund provided to take care of it so that the expiration of the physical life of the old unit finds us with sufficient funds on hand to purchase a new one of the same kind.

Obsolescence, on the other hand, will frequently demand that a unit which has been doing its work as economically as it was designed to do, which has entailed only slight repair charges, and which has many more years of useful life remaining, be scrapped and replaced by some other type of equipment which has been found to do the work more economically and satisfactorily.

Replacements of reciprocating engines by turbines, of small turbines by larger turbines, of hand firing by mechanical stokers, of hand regulation of feed water by automatic regulation and similar substitutions throughout the power plant are examples of the effect of obsolescence or economic depreciation.

It is true that natural depreciation, on account of repair and renewal expense, may have increased to such an extent that new equipment of any kind which will do the work more economically must be purchased; it is frequently therefore an item of great influence which may cause the buying of a different type of machine than that which has been used. When purchasing, we would without question, buy the most up-to-date equipment on the market, provided it could be installed, and which would, ordinarily, be not only more economical as concerns expenditures for repairs, but likewise more efficient in other respects because it has improvements as a result of invention and discovery. In this way the wear and tear due to physical depreciation is an influencing element, which is frequently of great importance when replacement on account of obsolescence is to be considered.

On the other hand there are many instances where despite large expenditures for repairs it is better to keep the old equipment running than to purchase new because the savings due to increased operating efficiency do not equal the loss occasioned by the expense of removal of the old equipment and the annual charges on the more expensive new equipment. It is then simply a case of retaining the old equipment a little longer until repair bills increase in still larger proportion, so that replacement is justified on this score, or if these remain fairly constant, until the invention of another machine which is enough more efficient than the one just considered, to warrant the replacement.

Another important factor which enters into a discussion of the need for improvements is that of the adequacy of present facilities.

The future growth of the demand for a plant's output can, in some cases, be predicted on the basis of past records, and many power plants are designed accordingly.

The needs of industry, however, are so varied and are subject to influence by such diverse factors, especially in a new and growing community, or a new industry, that calculations based on past demands for power are of doubtful value and the average designer of power plants is justified in providing machinery adequate only for the natural expected growth in the immediate future. By the time that the natural growth of the demand on the plant has exceeded its available output more up-to-date and economical machinery, according to the past record of development in the power plant field, will likely have been invented; additions to the power generating equipment naturally should be of the newer type, therefore interest on money which has been tied up in unused machinery would be lost in any case, and if such equipment became obsolete in the meantime the loss of a large portion of the capital investment would also be incurred.

The wise engineer, therefore, does not build too far into the future; he limits his investment to needful equipment, and consequently we find the capacity of the power plant overtaxed rather than the contrary.

In our discussion thus far we have seen that the question of improvements, how and when they should be made, depends on any one, two or all of three factors —(1) obsolescence—(2) inadequacy—(3) natural or

physical depreciation—and efficiency as related to all three. These will now be discussed in greater detail and methods pointed out by means of which the engineer can determine when machinery should be replaced or new machinery added; when equipment has reached its limits of usefulness by wear and tear, obsolescence or inadequacy.

Replacements Due to Obsolescence and Inadequacy

To compare the relative economies of the old unit and the new the method known as the method of annual expense will be used.

The annual expenditure for operation of any unit consists of three factors, namely (1) interest on capital invested, (2) equated annual cost of operation including cost of labor, fuel, repairs, taxes, etc., (3) an annual payment into a depreciation fund which if left to accumulate with other similar payments would, at the expiration of the life of the unit, be equal to the cost of a new unit.

That the first two factors mentioned above are items of expense will be readily conceded. The nature of a depreciation fund, what it is, why it should be considered an item of expense and how payments into it are made is a matter of considerable controversy and requires some explanation.

The Nature of Depreciation Funds

Briefly, then, a depreciation or reserve fund is used for the purpose of keeping the initial investment intact. The minute a piece of equipment is installed in a power plant it begins to depreciate in value because of obsolescence, inadequacy or physical depreciation which have been defined heretofore. Now then, if the plant is supplying power and light to a manufacturing plant, for instance, and we figure the cost of furnishing the power on a basis of interest on investment and cost of operation alone, the time will come when the plant unit has depreciated to such an extent that it requires renewal and we must have capital with which to buy the new unit.

We cannot add this new capital to our previous investment and say that as we have added $1000 to the original $1000 investment, we have $2000 and therefore our interest charge should be based on that sum, because our initial investment has been wiped out; the machine is scrapped and we only have a total of $1000 all told (assuming for the purpose of this discussion that the scrap value is 0) invested in producing equipment. Are we to charge this $1000 in scrapped equipment to loss and deduct it from dividends? Manifestly this is not just, because we have a right to expect that the loss in productivity of our equipment will be paid for by the user of power. Therefore we shall be paid by the user of our power or light annually or charge against his department, a sum, in addition to interest on capital and cost of operation, such that the value of our original investment will remain intact, so that at the expiration of the life of the unit, we will have a fund equal to the cost of a new replacement unit and can retire the old.

If we do not include this depreciation charge, we are figuring our costs too low and the user of our power is getting the benefit of our error, and if we do not provide a separate fund in our accounting system so that a certain sum will be set aside out of surplus for renewals, we will declare larger dividends than justifiable and subsequent dividends, when the plant is at the end of its life and is about to be renewed, will suffer accordingly.

Although engineers and accountants are practically agreed as to the necessity for a fund they are divided as to the method to be used in providing it.

Two General Systems for Establishing Depreciation Funds

There are two general systems in use to establish depreciation reserve funds, known respectively as the straight line method and the sinking fund system. In each case a sum is set aside annually to accumulate until the expiration of the life of the unit, and in each the total amount so set aside will be equal to the original investment. At intermediate points, however, the amount in the depreciation fund on the straight line basis will be greater than the amount on the sinking fund basis and inasmuch as our problem is to find when in the life of the plant it has ceased to be economic it is important that we determine just how far this difference in the annuities will affect our decision.

The amount set aside on the straight line basis is found by dividing the first cost less the scrap value by the estimated total life in years to give the depreciation annuity.

Suppose we have a unit costing $100, which has a scrap value of $13 and an estimated life of 19 years. The depreciable value is $100 - 13 = 87$. The annual payment will be $87 \div 19 = \$4.58$. This system commends itself on account of its simplicity of application, but fault is found with it as being inaccurate and not comparable with actual conditions. It is inaccurate because no account is taken of the interest earned by the depreciation fund, which, in this case if compounded annually at 5 per cent would amount to $39.15 and we would therefore be charging too much by that amount for the use of our product. We might assume that the fund is not invested, but this is not likely: either the amount so set aside will be invested in the plant and earning the same rate of interest as the other money invested in the business, as is customary in most plants, or it will be placed as a separate fund in a bank to draw compound interest. Therefore we must reduce our payment of $4.58 so that it with its compound interest will amount to $87; such a payment will be $2.85 which is the same as that required on the sinking fund basis.

With the sinking fund basis an equal sum is set aside annually to draw compound interest. The capital remains fixed so that interest charges are constant and therefore total of interest and depreciation is constant during the life of the unit. The depreciation annuity of $2.85 accumulates yearly until at the expiration of life it amounts to $87.00 which added to the $13.00 scrap or salvage value makes up the $100 needed to buy a new unit. In this case our depreciation annuity is found from ordinary sinking fund tables or by the formula:

$$D = \frac{r}{(1+r)^N - 1}$$

in which D = amount set aside annually for each dollar of cost

r = rate of interest

N = years estimated life of plant.

The sinking fund methods can be shown to be much more equitable for use in the computation of depreciation reserves than is the straight line formula and will, therefore, be made use of in further discussion.

In developing formulas for comparing the annual expenses of a new and the present unit, we find therefore, interest on capital invested, equated annual cost of operation, and the depreciation annuity to be the three principal factors. We will use as the basis for comparison the unit cost depreciation formula, developed by H. P. Gillette.

In the following by the term "old plant" is meant the present plant or plants units; by "new plant" is meant the most economic new plant or unit which could be purchased.

In this formula capital letters refer to new plant, small letters to old plant.

C = First cost of the new plant.

c = First cost of the old plant.

D = Depreciation annuity for *total* natural life.

d = Depreciation annuity for remaining natural life.

E = Equated annual operating expenses (including taxes) during entire life of new plant, inclusive of cost of repairs and natural depreciation, but exclusive of functional depreciation annuity.

e = Same for old plant during its remaining life.

F = Functional depreciation annuity rate for new plant.

f = Functional depreciation annuity rate for old plant.

K = Total equated or true annual cost during *entire* life of new plant.

k = Total equated annual cost during *remaining* life of old plant.

N = Total life of new plant in years.

n = Remaining life of old plant in years.

R = Interest rate plus functional depreciation rate.

r = Interest rate including risk insurance, taxes, and proprietary supervision (management) not included in F, f, E, e.

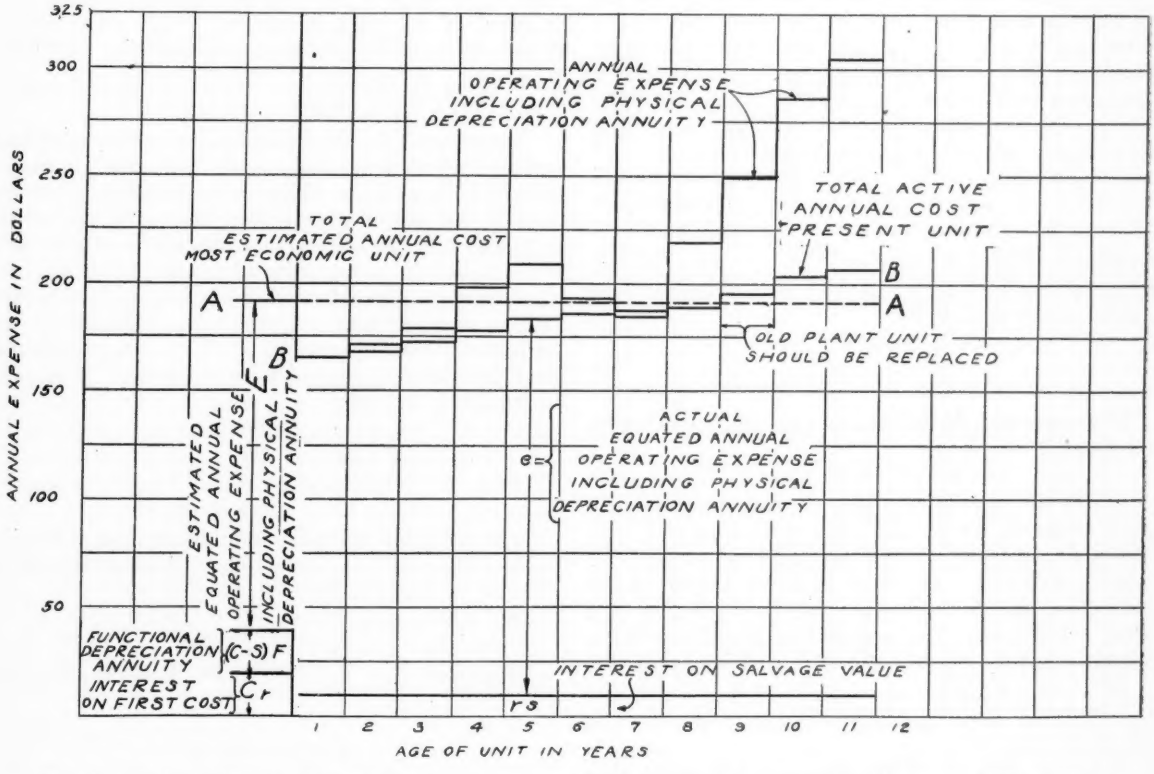

325
300
250
200
150
100
50
ANNUAL EXPENSE IN DOLLARS
ANNUAL OPERATING EXPENSE INCLUDING PHYSICAL DEPRECIATION ANNUITY
TOTAL ESTIMATED ANNUAL COST MOST ECONOMIC UNIT
TOTAL ACTIVE ANNUAL COST PRESENT UNIT
A
B
OLD PLANT UNIT SHOULD BE REPLACED
ESTIMATED EQUATED ANNUAL OPERATING EXPENSE INCLUDING PHYSICAL DEPRECIATION ANNUITY
ACTUAL EQUATED ANNUAL OPERATING EXPENSE INCLUDING PHYSICAL DEPRECIATION ANNUITY
FUNCTIONAL DEPRECIATION ANNUITY (C-S)F
INTEREST ON FIRST COST Cr
INTEREST ON SALVAGE VALUE
rs
1 2 3 4 5 6 7 8 9 10 11 12
AGE OF UNIT IN YEARS

FIG. 1. CHART SHOWING HOW TO DETERMINE WHEN TO DISCARD A UNIT ON ACCOUNT OF OBSOLESCENCE OR INADEQUACY

S = Salvage value of new plant.

s = Salvage value of old plant.

U = Unit cost of product of new plant.

u = Unit cost of product of old plant.

v = Depreciated value of old plant.

Y = Annual output in units, new plant.

y = Annual output in units, old plant.

from which we have:

$$U = \frac{K}{Y} = \frac{Cr+E+(C-S)F}{Y} \qquad (1)$$

and

$$u = \frac{k}{y} = \frac{vr+e+(v-s)f}{y} \qquad (2)$$

Now if the unit cost, u, of the old equipment is more than the unit cost, U, of the product of the new equipment, it will pay to purchase the new one. On the other hand where u is less than U the present plant is cheaper to operate. It is a plain case of substitution in the above formula. When the production cost in the old unit is equal to that in the new a condition of equality exists which enables us to make certain decisions of value. Thus we can say that the old plant is as economical of operation if its unit annual cost of production is the same as that of the most economical new plant or

$$\frac{Cr+E+(C-S)F}{Y} = \frac{vr+e+(v-s)f}{y} \qquad (3)$$

if the right hand member of the equation is less than the left hand member it is cheaper to retain the old unit; if it is greater, then it is time to sell or scrap the old and buy the new unit.

We can look at the problem also this way: If it is time to replace the old equipment with the new it has reached the end of its economic life, in other words its depreciated value is equal to its scrap value and $v = s$, therefore the equation becomes

$$\frac{Cr+E+(C-S)F}{Y} = \frac{rs+e}{y} \qquad (4)$$

which expresses the relation when the old plant has just reached its age of retirement. If the new plant is more economic than the old

$$\frac{Cr+E+(C-S)F}{Y} < \frac{rs+e}{y} \qquad (5)$$

If the new and old units have the same output $Y = y$ and equation 4 becomes:

$$Cr+E+(C-S)F = rs+e \qquad (6)$$

It will be observed then that a depreciation annuity is not computed for the old plant to be compared with a term of like kind in the left hand member of the equation, and this is explained as shown before, by the assumption that the old plant can be purchased at a value, v, which can be no greater than its salvage value, s, if the plant has reached the limit of its economic life.

In order to apply this formula to a test problem it is necessary that we understand just what the symbols in it stand for.

We know that C = First cost of a new plant unit, r = rate of interest, including risk insurance, etc., but not including the depreciation annuity "F." E is the equated annual (not average) operating expenses for a period of years, formed by the sinking fund method of calculation. This is done by taking the total cost of repairs, labor and other items for the first year and finding what this would amount to at compound interest for the years remaining in the estimated life of the plant. Similarly the operating expenses for the second, the third and the fourth year are each compounded for the total life of the plant. All these compounded repair costs are then added and multiplied by the annual deposit in a sinking fund which if started at the beginning of the life will equal $1 at the expiration of the economic life of the plant unit. The resulting product is the equated annual operating cost.

F, the functional depreciation rate, is the annuity set aside, the same as insurance premiums, each year for the estimated economic life based on the years that a unit of this class remains in use before it becomes obsolete or inadequate and is replaced by an improved or larger unit. Wear and tear or physical depreciation is not included in the functional annuity. The history of most power plant equipment has shown that it has become obsolete long before it has depreciated seriously on account of physical wear and tear and although most so-called "life" tables showing average estimated life of power plant units do not specify whether physical or economic life is meant, except in the few cases where obsolescence and inadequacy are obviously not the reason for scrapping the equipment, it may be assumed that the "lives" given are functional and the depreciation annuity corresponding to this, used accordingly. The functional depreciation rate is taken from sinking fund tables and is the amount which annually compounded at the interest rate "r" will redeem $1 at the conclusion of the estimated functional life "N" years.

In order to show the applications of this formula we shall assume the following conditions:

The unit is 4 yr. old; we find that a new unit has been invented which seems to be more economical; it has an estimated life of 15 yr. while our old unit has apparently reached the end of its economic life. The cost of the new unit will be $500. Its scrap value will be $100 which is also the scrap value of the old unit. The rate of interest will be taken as 4 per cent although rates from 6 to 8 per cent are common. According to our records the operating expense of the present unit including a physical depreciation annuity based on its assumed physical life, follows:

1st year....$300
2nd year.... 325
3rd year.... 375
4th year.... 450 estimated.

The estimated equated operating expense of the new plant will be $275. Are we justified in scrapping the old unit for the new?

We have equation 6:

$Cr + E + (C - S) F = rs + e$

Substituting: $C = 500$; $r = .04$; $E = 275$; $S = 100$; $F = .04994$; $e = 375$.

Then

$$354.98 < 400.08$$

Hence we shall save $400.08 - 354.98 or 45.10 annually by scrapping the old and buying the new equipment.

This sum capitalized at $4\% = \frac{45.10}{0.04} = \$1127.50$, or the actual present worth of the change.

We have assumed that the number of units of production is the same for the new as for the old unit. In most cases this is not so, as the new unit generally has a greater volume of production than the other. Suppose in our case the new unit produced 100 items as against 60 for the other. Then our unit cost of production would be $\frac{354.98}{100.00} = \$3.55$ in the first instance, and $\frac{400.08}{60} = \$6.67$ in the other, or a saving of

$\frac{6.67 - 3.55}{6.67} = \frac{3.12}{6.67}$ over the original cost = 46.8 per cent.

In order to make the method of equating operating expenses a little clearer we show herewith the actual computations used in the preceding example.

The equated annual operating expense of the old unit is computed as follows: Total estimated economic life = 4 year.

Principal	Compounding period, years	Rate[1]	Amount
300	3	1.1249	337.47
325	2	1.0816	351.52
375	1	1.04	390.00
450	0	1.00	450.00
		Total,	1528.99

Amount which if invested at 4 per cent compound interest will accumulate $1 at the end of 4 yr. is 0.23550[2]. Multiplying this by 1528.99 gives 360.08 as the equated annual operating expense. In this the average annual operating expense computed as ordinarily would be $\frac{300 + 325 + 375 + 450}{4} = 362.50$, a difference of $2.42 which is not a material difference. If the annual operating expense had been the same in each year then the average annual expense would have been the same as the equal annual expense.

Although some engineers and accountants attempt to use the straight lines or sinking fund formula for the purpose of arriving at the actual value of a depreciated plant it can be shown that except in a few special cases where there are many units of all ages in all stages of depreciation, such for instance as railroad ties or telephone poles, the use of these formulas is not warranted. In the case of many similar units we can say for instance that if they are all of equal value and in all stages, from new to those being taken out of service, that their average depreciated value is 50 per cent of the original cost. We know however of many units which, when half of their estimated life has expired, are certainly worth more than half of their original cost, which is the value placed upon them by the advocates of the straight line system because depreciation annuity $= \frac{C - S}{N}$ Therefore where $n = \frac{N}{2}$

$$\text{Depreciation to date} = \frac{C - S}{N} \times \frac{N}{2} = \frac{C - S}{2}$$

And the total remaining value is taken

$$\text{as } (C - S) - \frac{C - S}{2} = \frac{C - S}{2}$$

The sinking fund formula is likewise in error by an equally similar assumption unless it can be shown that operating and repair expenses have been uniform which is rarely if ever the case with depreciated plant.

So we again make use of the unit-cost depreciation formula, and when Y = y and S = s and F = f as they frequently do, then we can write equation (3) in this form:

$$v = C - \frac{e - E}{r + f} \qquad (7)$$

Therefore, if the operating expenses of the new unit are equal to those of the old, the expression

$$\frac{e - E}{r + f}$$

in this equation becomes equal to zero and equation (7) becomes

$$v = C$$

Or the depreciated value of the old unit is equal to the cost of the new unit; therefore

"If it cannot be shown that the substitution of a new plant unit or group of units will decrease average expenses, then the value of the old unit is as great as the value of a new plant unit."

As a practical application of the foregoing equations let us suppose that we have a plant unit which has been running along for a number of years and we desire to find its present value, knowing the cost of the most economical plant of equal capacity, and its estimated equated annual operating expense, and the equated annual operating expenses of our present plant from our records. Let C = $1500, E, the estimated annual expense not including the functional depreciation annuity but including the natural depreciation annuity = $50, e for the old plant = 80; r = .04, f = .02

$$\text{Then } v = 1500 - \frac{80 - 50}{.04 + .02} = 1000$$

or the depreciated value of the old plant is $1000.

Replacements Due to Natural Depreciation

In the preceding discussion on obsolescence and inadequacy we have considered the criterion by which we are able to determine when the invention of a more economical type of machine makes it advisable for us to substitute it for our present equipment. Relative operating expenses constitute the hub of the discussion, and among these expenses is the cost due to repairs and natural depreciation which in some cases may therefore be the principal contributing factor that makes a modern unit more economical of operation than the older one. That repair expense is not a factor in many cases we know because it is possible that a machine has been purchased just before a newly invented one, which may revolutionize an industry, has appeared on the market. It is possible therefore that without spending a cent for repairs our newly purchased machine has suffered 75 per cent functional depreciation. Just how much value it has lost we can only determine by using equation (6) in which the *total* operating expense (and in this case the repair item will be nil) is the basis by which the relative economy is determined.

On the other hand there are cases in which obsolescence does not cut any figure—those cases in which the standard of efficiency for certain types of unit, such as boilers, Corliss engines, etc., has apparently reached its practical limit—and where physical depreciation of a unit due to wear and tear has progressed to such a point that the question comes up as to whether it is advisable to scrap the old unit and buy a new one of the

1. From compound interest tables based on the formula $(1+r)^n$, in which n=number of year.
2. From sinking fund formula based on the formula $\frac{r}{(1+r)^n - 1}$, in which n is the same as above.

same or approximately the same kind. We will assume then that our worn out unit is neither obsolete nor inadequate, but that wear and tear only have caused it to appear to be less efficient than a new unit of the same kind.

Equation 5

$$\frac{Cr + E + (C - S)F}{Y} = \frac{vr + e + (v - s)f}{y}$$

can then be rewritten, inasmuch as the functional depreciation is non-existent and factors F and $f = 0$, in the form

$$\frac{Cr + E}{Y} = \frac{vr + e}{y} \quad (8)$$

In using this formula C is the cost new of a plant unit of the same size and class as the old unit whose depreciated value is v, E is the equated annual operating expense including a depreciation annuity required for a sinking fund to equal the full wearing value

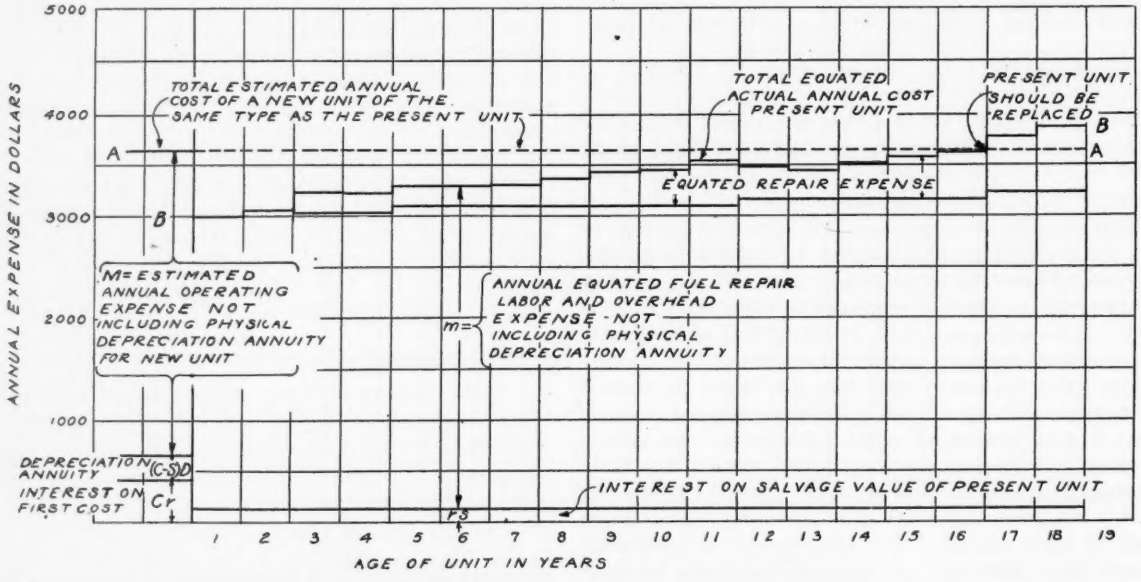

ANNUAL EXPENSE IN DOLLARS
5000
4000
3000
2000
1000
TOTAL ESTIMATED ANNUAL COST OF A NEW UNIT OF THE SAME TYPE AS THE PRESENT UNIT
TOTAL EQUATED ACTUAL ANNUAL COST PRESENT UNIT
PRESENT UNIT SHOULD BE REPLACED
A
B
EQUATED REPAIR EXPENSE
M= ESTIMATED ANNUAL OPERATING EXPENSE NOT INCLUDING PHYSICAL DEPRECIATION ANNUITY FOR NEW UNIT
m= ANNUAL EQUATED FUEL REPAIR LABOR AND OVERHEAD EXPENSE NOT INCLUDING PHYSICAL DEPRECIATION ANNUITY
DEPRECIATION ANNUITY (C-S)D
INTEREST ON FIRST COST Cr
INTEREST ON SALVAGE VALUE OF PRESENT UNIT
Fs
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
AGE OF UNIT IN YEARS

FIG. 2. CHART SHOWING HOW TO DETERMINE WHEN TO DISCARD A UNIT ON ACCOUNT OF PHYSICAL DEPRECIATION

(C — S) during N years *total natural* life of the unit.

Similarly e is the equated annual operating expense of the old plant including the depreciation annuity required for a sinking fund to redeem the remaining wearing value (v — s) during the *remaining natural* life of n years. We accentuate the annuity items to impress the idea that these are for natural life and not functional life. Inasmuch as most life tables are apparently based on functional life they are practically valueless in making up physical depreciation annuities and the physical life must be carefully worked out.

Then if M and m are the annual operating expenses other than depreciation of the new and depreciated units respectively;

$$E = D(C - S) + M \quad (9)$$

$$e = d(v - s) + m \quad (10)$$

and formula (8) can then be written.

$$\frac{Cr + D(C - S) + M}{Y} = \frac{vr + d(v - s) + m}{y} \quad (11)$$

but when the old plant has depreciated so that it has ceased to be economical, its value is no greater than its salvage value and $v = s$.

Therefore $\frac{Cr + D(C - S) + M}{Y} = \frac{rs + m}{y}$ (12)

If the old unit produces as many units of product as the new, $Y = y$ and we have

$$Cr + D(C - S) + M = rs + m \quad (13)$$

To illustrate the use of this formula we will assume the following:

Cost of new plant unit = \$2000.

Estimated life = 40 yr.

Estimated equated annual cost of operation new unit = \$300.

Rate of interest = 4 per cent.

Equated annual operating expense old plant unit from records = \$360.

Salvage value new and old plant = \$400.

Then $C = 2000$; $r = .04$; $D = 0.01052$; $M = 300$; $m = 360$; $s = 400$

and by substitution

$$396 > 376$$

Since the right hand member of the equation is less than the left it will pay us to retain our present equipment. In this case we save \$20 annually. As soon, however, as equated annual operating expenses of the present unit increase by \$20, we should scrap it in favor of the new.

We have assumed, in the preceding, that the output of the two plant units was the same. If, however, they are not and $Y = 900$ and $y = 800$ then

$\frac{396}{900} = \$0.44$ = Unit annual cost of production by new plant unit

$\frac{376}{800} = \$0.47$ = Unit annual cost of production by old plant unit

and therefore the new plant is the better investment.

When $Y = y$, $S = s$ and $D = d$

as they frequently are, equation (11) can be rewritten in the form

$$v = C - \frac{m - M}{r}$$

which enables us to evaluate an old plant in terms of the new. When the second half of the right hand member = O then v = C so that we can say:

If functional depreciation (obsolescence and inadequacy) are absent, and with equal annual output and salvage value and equal prospective physical life the depreciated value of the old plant unit is equal to cost of a new unit of the same kind minus the capitalized difference in their equated annual operating expenses during the prospective physical life.

Graphically Determining When Replacements Should be Made

Using formula (6) and data from the plant operation records we are enabled to plot a graph similar to that shown in Fig. 1 whereby we can determine when it is time to retire the old plant unit on account of obsolescence or inadequacy in favor of a more economical unit.

The annual operating costs are plotted each year. In these are included an annuity factor to take care of physical wear and tear based on the estimated physical life of the plant which ordinarily will be greater than its estimated functional life. Other items included are the share of the total plant costs for labor and fuel which can be assigned to the unit in question, also the cost of repairs and supplies and the share of taxes, insurance and other general expense items apportioned to the unit. From the annual operating costs are computed the equated annual operating costs. For most purposes, however, the average annual expenses of all years up to and including the one in question and divided by the number of years, is equal nearly enough to the equated annual expense computed on a sinking fund basis and which we have described elsewhere, to be used in its place. The remaining portion of the annual cost, the interest on the salvage value of the depreciated plant is readily calculated. The equated annual operating cost and the interest on salvage value make up the total of the annual cost which is plotted on the graph from year to year.

On the left-hand side of the graph are plotted the estimated annual cost of the most economical unit which will do the work of the present one. In this we include interest on first cost of unit, a functional depreciation annuity based on the estimated functional life of similar units, and the estimated annual operating expense.

It must be remembered that we are not comparing the total expenses of two units to determine their relative economy. In that case we would also include a functional depreciation annuity for the old unit. What we are doing is assuming that the going value of our present unit has dwindled so that its only value is its salvage value and our functional annuity then becomes 0. The difference in the level of the expense line of the old unit as compared with the new in the first years of the life of the old unit shows, not that the old unit costs less to operate than the new, but, that we cannot afford to scrap it since its value to us is greater than its scrap value by the difference between the level of A-A and of B-B, less the functional depreciation annuity, F (C—S), capitalized at the rate "r."

As our annual expense increases the time comes when our equated annual expense line B-B crosses the estimated annual expense line A-A of the most economical new unit and it is then time to scrap our old unit. This, in Fig. 1, is shown to be at or during the ninth year of service. Thus our annual expense line enables us to foretell to some extent the approach of obsolescence or inadequacy of our present unit.

If a more economical unit than the one we have originally considered as the most economical is invented in the meantime, our line A-A comes down correspondingly and will intersect the line B-B at any earlier date reducing the economical life of our present plant accordingly.

On Fig. 2 we have plotted a similar graph to that in Fig. 1, but instead of considering replacements due to obsolescence or inadequacy we have considered only those due to physical wear and tear, it being assumed that our present unit is adequate and that none other can be purchased which is more economical than the present one, excepting a new one of the same kind or type, in other words obsolescence and inadequacy are eliminated from the discussion.

As a functional depreciation annuity does not enter into the cost of operation of a functionally obsolete unit, and was eliminated on that account, in considering the old unit in Fig. 1, so the natural or physical depreciation annuity is similarly eliminated in the case of the old unit in Fig. 2. The other elements of expense are substantially similar to those in Fig. 1. The equated annual expense has been obtained as previously described but the annual expense has not been shown on this chart.

It will be seen that the equated annual repair expense is the deciding factor which determines the physical life of the unit; as repairs increase the line of total annual costs B-B is forced up until it crosses the line A-A at 17 yr., which indicates that the limit of the economical physical life of the unit has been reached and that it should be replaced.

Use and Importance of Records

During our discussion of the subject of improvements it will have become evident that records of performance showing costs and corresponding efficiency and quantity of production play an important part in furnishing data by which to determine when replacements are necessary. Mere guess or the use of age-life formulas, without consulting tests and carefully examining the records, as is sometimes done, is misleading and manifestly a far from satisfactory method to be used in ascertaining the truth. Tests of a steam engine will determine its fuel consumption as compared with that of a new engine or turbine. Inspection will show the condition of bearings, piston rings, packing, etc., and show how much will need to be expended for repairs and the probable date of renewal. Knowing the corresponding costs for a new engine or turbine we will act accordingly. Similarly if our records show that the boiler repair costs are increasing rapidly and shut downs are increasing in number and duration, if our load is continually exceeding the rated capacity it is time to consider the advisability of scrapping the boiler and with the aid of our charts and formulas we can find the true status of the case.

Coal Weighing Devices and Meters

Their Construction and Mode of Operation

AS COAL is the largest single item in the cost of production of heat, light, power, and refrigeration, it is vitally important that some means of weighing or measuring this commodity be employed. Installation of elaborate and expensive weighing devices or meters is hardly warranted in small plants; but the employment of some form of platform scale by means of which each car, truck or wheelbarrow of fuel may be weighed is not only desirable but necessary for determining the consumption of coal and to serve as a check against the statements of the mine operator or dealer. Generally, however, and especially so in the case of the larger power houses other methods are preferable and particularly so when the weighing or measuring device is more or less automatic in operation.

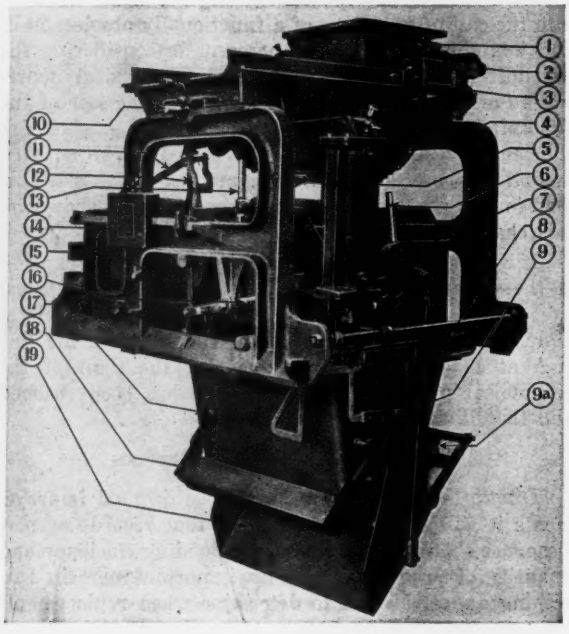


FIG. 1. AUTOMATIC COAL SCALE WITH DEFLECTOR REMOVED TO SHOW FEED HOPPER AND INLET GATE

A typical automatic scale and one which may be installed directly in the path of the fuel either as it is delivered to the receiving hopper or bunker, or as it leaves the bunker on its way to the stoker or furnace, is shown in Fig. 1. After passing through a feed hopper fitted with an eccentric driven agitator to keep the fuel in motion, the coal passes through an inlet gate from which it falls into a weigh hopper carried at one end of an equal-arm beam from the opposite end of which is suspended a weight box. These, which are of equal weight, balance one another when empty.

On intermittent-service scales, a throw-out gear or clutch is provided on the agitator shaft to stop the agitator whenever the feed gate closes. As the feed gate again opens, the clutch which is interconnected with the operating mechanism of the gate is engaged and the agitator is again set in motion.

From the gate the coal falls into the weigh hopper and continues until the weight of the coal equals that of standard weights placed in the weight box whereupon the beam balances and the supply is cut off. Automatic discharge from the weigh hopper, closing of the hopper door and reopening of the feed gate follow in turn.

The scale shown in Fig. 1 is a 200-lb. unit with coal deflector removed to illustrate the feed hopper and inlet gate. The scale is shown in the discharge position. Feed gate 4 is closed. Toggle 11 is at dead center and the release gear for the discharge door 6, 7, 9 is unlocked and opened. When the weigh hopper descends, trigger

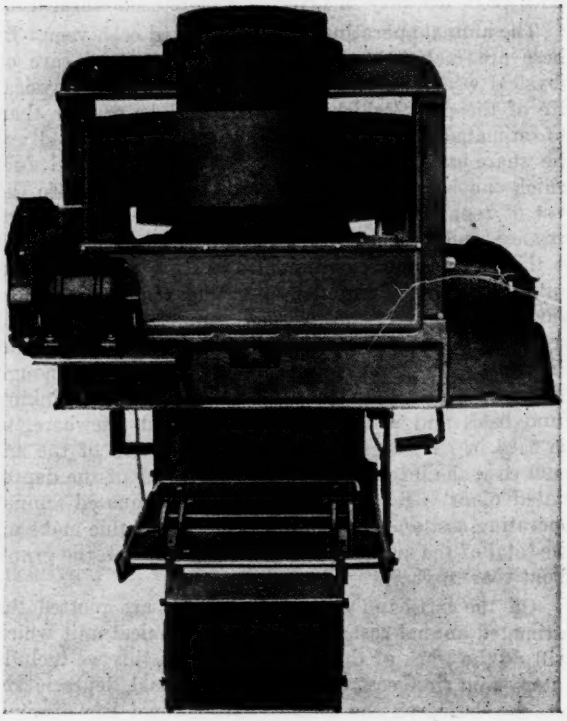


FIG. 2. AN AUTOMATIC COAL SCALE EMPLOYING MOTOR CONTROLLED FEED

arm 12 is tripped, allowing bar 15 to fall and lever 16 to come up and strike arm 6, knocking it from the horizontal position where the centers of the toggle were in line and locked to such a position that the load on the discharge door is able to open the door. In opening, interlock 8 is moved to one side, thus preventing lever 16 from descending, which it must do before the dead center of lever 11 can be broken and the feed gate again opened. As soon as the hopper is empty it is raised by the weights in the weight box, pushing up pendant 13 and also raising counterweight 5. On 300-lb. scales and those of greater capacity there is a dashpot piston arranged inside of the cylinder so that in addition

to acting as the counterweight for opening the gate when the toggle is broken, the dashpot acts as a spring to prevent sudden shocks and vibrations.

Each weighing is recorded automatically by a six-fingered reciprocating engine-type springless counter 3, and since each draft is always the same the exact weight of coal received or used in any given time interval can be obtained by multiplying the number of weighings by the total of standard weights in the weight box.

Receiving scales of 500-lb. and greater capacity may

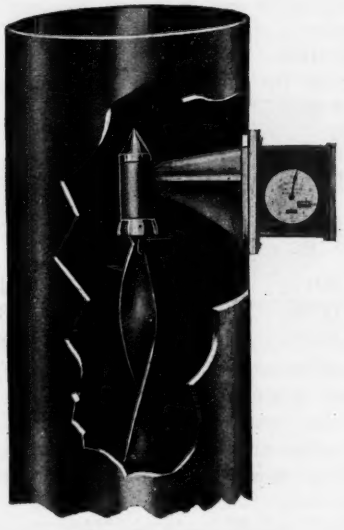


FIG. 3. COAL METER OF THE HELICAL VANE TYPE

be provided with residue scales to weigh partial loads if any such remain.

In the automatic coal scale pictured in Fig. 2, the fuel is delivered from the overhead bunker through a pipe attached to a casting forming a part of the scale frame. This casting is placed about 5 in. above a horizontal circular rotating disk and in such a manner that the coal is deposited upon this disk in the form of a

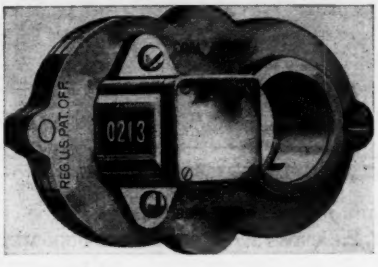


FIG. 4. COAL METER FOR USE WITH UNDERFEED STOKERS

cone. Above this disk is a stationary casting which serves to plow or scrape off a certain amount of coal into a cast-iron weigh hopper.

As the amount to be weighed is approximated, a delicately balanced scale beam begins to tip downward. The first part of this motion throws out the clutch driving the feed disk and stops the discharge of coal into the hopper. A sliding weight serves to compensate for the amount of coal momentarily in suspension, and makes the net weight of coal actually delivered to the hopper the net weight desired. The second part of the downward travel of the weigh hopper trips the balanced gate serving as a hopper bottom, and the entire amount of coal is instantly dumped.

If the clearance is sufficient, when the last piece of coal clears the hopper bottom, the weigh hopper returns to its original position. The slightly overbalanced bot-

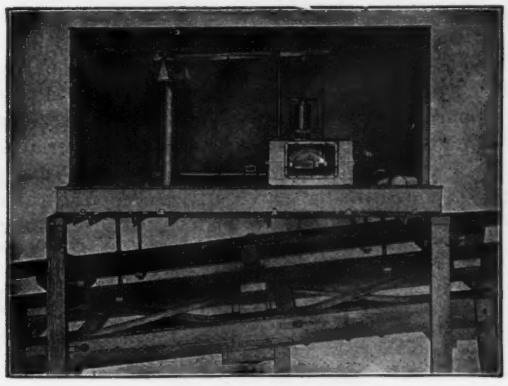


FIG. 5. DEVICE FOR WEIGHING COAL IN TRANSIT

tom first closes and then the driving clutch is thrown in and the feed resumed. It is possible to adjust the compensating weight at the second trial weighment and when this is once adjusted the scale will continue to operate within 1 per cent of accuracy.

An automatic counter which is furnished with each

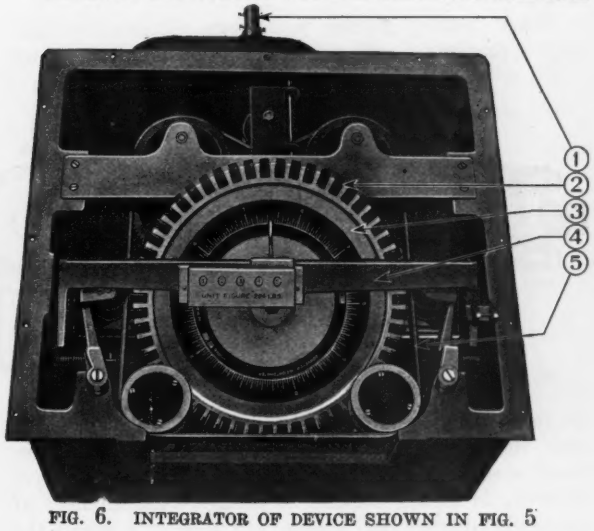


FIG. 6. INTEGRATOR OF DEVICE SHOWN IN FIG. 5

scale may be attached directly to the frame or at a distant point where it may easily be read.

Coal Meters

FIGURE 3 is illustrative of a typical coal meter which consists of a helical vane placed within a cylindrical conduit, generally the downspout from the bunkers. Movement of the coal causes the vane to rotate and the number of revolutions is a measure of the weight of coal passing. Rotation of the vane is transmitted by means of suitable shafts and gears to a counter operating a visible dial.

In the installation of this instrument care must be taken to avoid placing it in close proximity to an outlet or valve, a pipe too large or one which has become badly corroded and rough on the inside.

A coal meter designed for use with underfeed stokers having an accessible revolving shaft is shown in Fig. 4. At each revolution of the shaft, it registers one numeral on the dial and as each revolution signifies a certain amount of coal delivered to the furnace, the exact number of pounds fired in a given time is easily determined by multiplying weight per charge by the number of revolutions registered by the dial.

Weighing of coal while in transit may be accomplished by means of the weightometer shown in Fig. 5. The apparatus is an adaptation of platform scale with automatic float poise, and a mechanically operated integrator actuated from the scale beam. It is a self-contained unit with the conveyor. A section of the conveyor belt is supported on a floating platform, hung on compound levers, balanced by an iron float in a cylinder of mercury. The movement of the float is a direct measure of the weight on the conveyor belt.

The integrator illustrated in Fig. 6 multiplies the weight by the speed. Rollers are mounted around the periphery of disk 3. Belt 5, driven by the conveyor, rubs against the disk rollers at right and left. When the disk, which is carried on a swinging frame, is perpendicular to the plane of the belt (no load position) the rollers revolve and exert no turning effect on the disk; but, when the disk is tipped (accomplished by the leverage system), a component of the belt motion acts to turn the disk. The greater the weight on the belt the greater the tip and the faster the disk revolves. A simple mechanism records this motion.

Appliances for Measuring Water

THEIR CONSTRUCTION, PRINCIPLE OF OPERATION AND CHARACTERISTICS

FOR accurate work, water may best be measured by the use of two or more tanks resting upon platform scales and arranged to be filled and emptied alternately. In some forms of weighers no scales are employed. The number of dumpings are recorded by a counter, the total amount of water weighed being equal to the product of the number of dumpings and the weight of each charge.

When, however, other means are not available and only approximate results are desired, amount of water

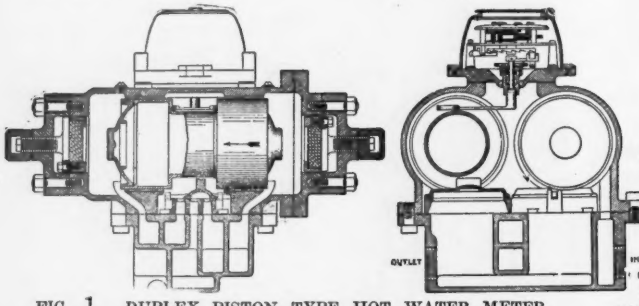


FIG. 1. DUPLEX PISTON TYPE HOT WATER METER

delivered by a reciprocating pump may be determined from the plunger displacement. Multiplying the sectional area in square inches of a single plunger, length of stroke in inches, number of plungers and number of strokes completed per minute will give as a result the number of cubic inches of water delivered per minute. From this should be subtracted loss due to slippage and when desiring to express the result in pounds per minute divide the net number of cubic inches by 1728 and multiply the quotient thus obtained by 62.425, the weight of 1 cu. ft. of water at greatest density (39.1 deg. F.). For other temperatures divide by the factors (by Kopp and Porter) given in the following table which indicates the relative volumes of water at different temperatures compared with its volume at 39.1 deg. F.

Deg. F.	Volume	Deg. F.	Volume	Deg. F.	Volume
39.1	1.00000	95	1.00586	158	1.02241
41.	1.00001	104	1.00767	167	1.02548
50.	1.00025	113	1.00967	176	1.02872
59.	1.00083	122	1.01186	185	1.03213
68.	1.00171	131	1.01423	194	1.03570
77.	1.00286	140	1.01678	203	1.03943
86.	1.00425	149	1.01951	212	1.04332

For measurement of flow of hot water, the piston meter shown in section in Fig. 1 is well suited. It is practically the water end of a duplex double-acting pump having the cross-over valve motion at the bottom. The moving parts consist of two plungers and two slide

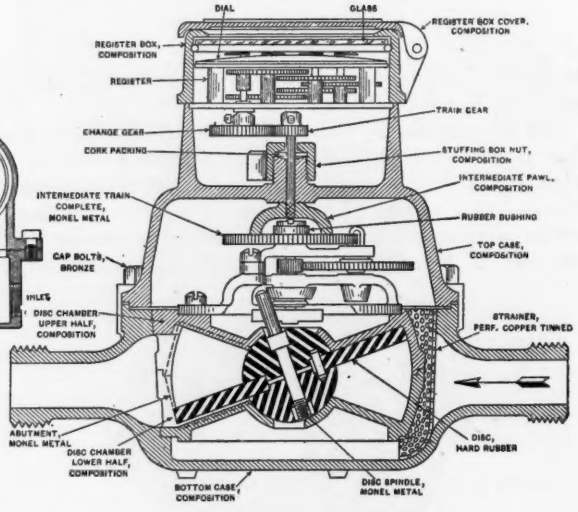


FIG. 2. CROSS SECTION OF FLAT DISK METER

valves with a lever which conveys the motion of the plunger to the recording mechanism.

By adjustable tappets at the ends of the cylinder, length of plunger stroke and consequently displacement per registration may be altered. This provides means for calibrating the meter for any service. When calibrating a meter of large size on a small quantity of water the counter moves but once for each complete revolution of the plunger; that is, each plunger must make one stroke forward and one return stroke before the counter moves once and it is essential, therefore, that the plunger should be started and stopped in the

same relative position in order to secure accurate results from the tests.

Another meter in extensive use and one quite accurate where a steady flow of the water or other liquid is maintained is the flat disk meter. This consists of a measuring chamber divided into two equal parts by a hard rubber disk, a gear chamber and a dial. One compartment is always filling while the other is emptying and thus an unbalanced water pressure moves the disk which in turn through the medium of a pin imparts motion to the integrating mechanism. Meters of this kind are suitable only where the temperature of the water being measured does not exceed 105 deg. F.

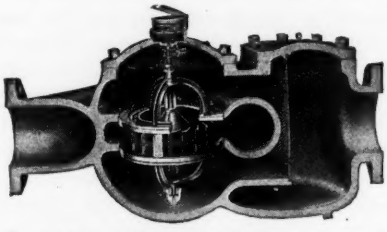


FIG. 3. SECTION THROUGH TURBINE TYPE METER

Shown in Fig. 3 is a typical turbine meter for use where large quantities of water are to be measured. Entering at the right the water passes through a screen, is deflected downward and by means of a central baffle plate is distributed horizontally and radially into a row of guide vanes which in turn conduct it through the vanes of a rotating impulse wheel connected to the metering mechanism. The wheel used is of hard rubber of practically the specific gravity of water and is carried on a vertical shaft turning on a jeweled bearing.

To record accurately the entire range of flows through large service pipes, the compound meter shown in Fig. 4 and consisting of a standard velocity meter and a standard positive displacement disk meter in combination with a vertical plunger valve all in a single casing has been developed. Its design is such that the action of the plunger valve (both up and down) is always sharp and positive; thus there is no "breaking point" in the registration where the flow changes from the disk to the turbine meter, and vice versa, when the point of change is reached.

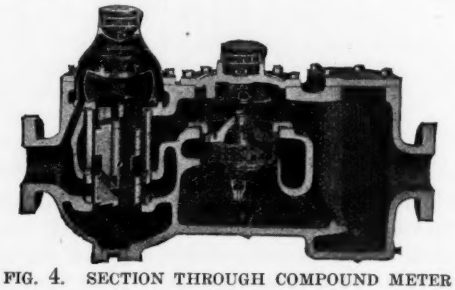


FIG. 4. SECTION THROUGH COMPOUND METER

On an ascending flow the full capacity of the disk meter is thrown immediately in the turbine, which starts and registers at once. On the descending flow the reverse action is the same, and there is no opportunity for the valve to flutter at the change point.

Testing Water Meters

For accuracy the only method of testing water meters is by weighing a quantity of water drawn through the meter and comparing this quantity with the counter reading. A full flow of water should come into the meter itself, the rate of flow to be regulated by a valve on the outlet side, thus insuring having the meter full of water and under pressure as in actual service. Whenever possible a quantity of water at least equal to a complete revolution of the hand on the first circle of the counter should be measured, as readings of fractions of the first circle are not sufficiently accurate.

FIG. 5. DIAGRAM OF VENTURI TUBE

Hot water meters should be tested only on hot water.

The Venturi Meter

For continuous measurement of water flow the Venturi type of meter is recommended. The principles are as follows:

When water flows through a pipe containing a contraction, or throat, as in Fig. 5, pressure at B will be less than at A, due to the increased velocity at B. In a properly designed pipe, however, this pressure drop will be almost entirely regained at outlet C, this in turn being due to the decrease in velocity after the water passes through throat B. These facts may be verified by inserting pressure gages at A, B and C. By means of a U tube containing mercury the drop of pressure between A and B may be accurately measured and always bears a definite relation to the rate of flow or velocity at B. Two small pipes connected to the inlet

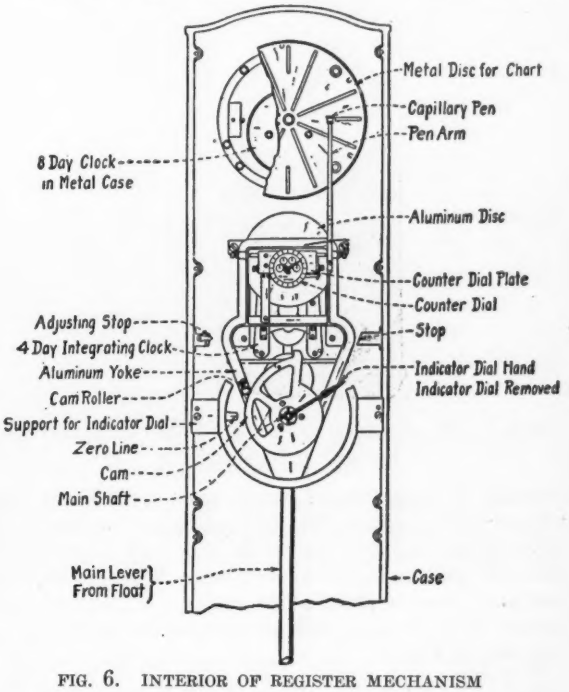


FIG. 6. INTERIOR OF REGISTER MECHANISM

and throat of the tube transmit the difference of pressure at these points to the meter or registering device. At the back of the register these pipes enter two large vertical wells, connected at the bottom by a small pipe, one well being subjected to the inlet and the other to the throat pressure of the tube. In each well is a heavy metal float resting upon mercury which flows from one well to the other in direct proportion to the difference of the two pressures, causing one float to rise as the other descends, the movement being transferred through rack and spur gearing to the indicator dial hand shaft. A cam on this shaft, Fig. 6, controls the position of the pen on the chart and also the degree of movement of the counter dial figures.

The register responds to minute variations in the rate of flow. The indicator dial is 30 in. in circumference and can easily be read to within ½ of 1 per cent,

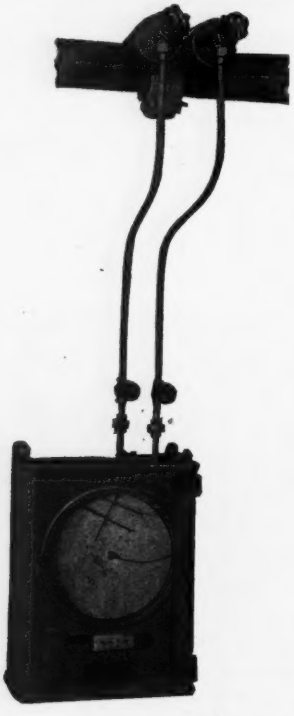


FIG. 7. FLUID METER EMPLOYING MERCURY BELL AND SCHEME OF CONNECTION

showing the exact rate of flow in pounds per hour. The counter dial registers the total pounds of water which have passed through the meter tube and is similar to the dial of an ordinary water meter. The recorder dial carries a circular chart which makes one complete revolution in 24 hr. and furnishes a continuous record of the rate of flow.

Orifice and Pitot Tube Meters

The meter shown in Figs. 7 and 8 operates upon the principle of accurately measuring the pressure difference across an orifice of 1/32-in. Monel metal placed between a pair of flanges in a pipe line as indicated in Fig. 7. Size of the orifice is proportional to the size of the pipe and the quantity and density of the fluid flowing through it; about ½ lb. pressure drop is secured at average rates of flow.

Details of the operating mechanism of this instrument are illustrated in Fig. 8. Valves H and L connect with the high and low-pressure sides of the orifice respectively while valve B is a bypass which serves to equalize the two pressures when desired. Within the bell casing, which when water or steam are measured is filled with water, is placed a mercury reservoir, a bell weight and a bell entirely closed except at its lower end and sealed by the mercury so that due to the pressure difference within and without the bell it is pushed upward, the degree of movement being proportional to the pressure difference. In normal or zero position of the bell, it is almost completely submerged in the mercury and is held within the mercury by the bell weight supported by a yoke fastened to the top of the bell. An increase in pressure difference forces the bell upward and as it rises from the mercury, the change in the buoyant action of the mercury on the walls of the bell balances the force due to the pressure difference.

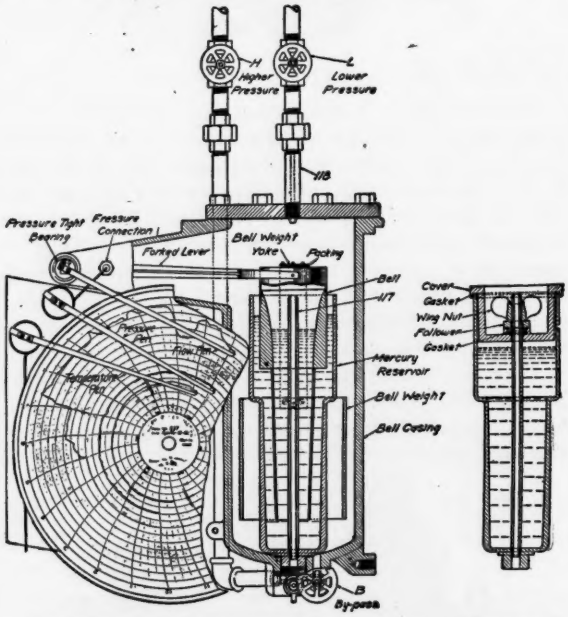


FIG. 8. CONSTRUCTION DETAILS OF METER SHOWN IN FIG. 7.

The shape of the bell is designed in accordance with the actual flow-curve (similar to a parabola) and corresponding to the pressure difference and the rate of flow through the orifice. A forked lever engages two pins in the yoke connecting the bell weight with the bell. The other end of the forked lever engages a squared section on the spindle, which serves both to guide the bell as it moves and also to transfer the motion to the recording pen and integrator.

An automatic shut-off prevents blowing out of the mercury or other damage when either of the pressures is excessive, due to abnormally high rate of flow, improper opening of valves, or the breaking of one of the connecting pipes. In case the higher pressure exceeds the lower by an amount corresponding to the maximum flow, the bell is forced to its extreme upper position and a soft packing held between the top end of the bell and the bell weight yoke which is exposed through a hole in each will close the opening in tube 118 thereby bottling up the water, which completely fills the casing and pre-

vents forcing the mercury out of the reservoir. In a similar way, tube 117 is sealed when the bell is forced down against it by excessive pressure in pipe L.

Pressure and temperature recording pens near the center of the chart are operated by helical tubes, connected respectively to the arm of the bell casing and a thermometer bulb located in the steam line.

Both chart and integrator disk are driven by a pendulum clock. The counter is suspended from a knife edge bearing on the clock frame and is moved across the disk by a connecting rod from an arm which projects down from the back end of the recorder pen shaft. The follower wheel of the integrator is in frictional contact with the clock-driven disk and is moved from the center out toward the circumference as the rate of flow increases from zero to the maximum capacity of the meter.

Where accuracy is in doubt, its performance may be checked with the instrument in place and under actual working conditions by the use of the CO_2 method of steam and water measurements mentioned elsewhere.

Either an orifice disk or a pitot tube inserted into the pipe where the flow is to be measured is employed to transmit the pressure difference created by the flow to a mercury column in the body of the meter shown in Fig. 9. Dynamic and static chambers are connected to the pitot tube or the pipe carrying the orifice, and when the meter is in operation, due to existing pressure differences the mercury level in the well is depressed while that in the contact chambers is raised in proportion to the impact of the flow.

Within the contact chamber is a resistance element made up of contact rods vertically suspended and connected to resistances held in position by two Bakelite disks; the contact rods are insulated by means of transil oil, which entirely fills the contact chamber above the mercury. The resistances are wound on a series of spools ending in a terminal post insulated from the meter body and forming a part of the circuit comprising the transformer, the meter body and the connected electrical instruments.

As the pressure difference increases, the mercury rises in the contact chamber and as the successive ends of the contact rods are of gradually decreasing lengths, each successive rod comes in contact with the rising mercury, thus cutting out a given portion of resistance. The resistances are so divided by the contact rods that the flow of the current in the circuit is directly proportional to the flow of the fluid in the pipe, and as a consequence the indicating, recording and integrating instruments used in connection with this meter operate accordingly. Actually these instruments are electric current flow meters, although they are made to read in units of fluid flow.

The mercury seal shown in Fig. 9 provides an automatic release which prevents derangement of the elements in the meter body when sudden changes of pressure occur in the line. The seal has two cylindrical compartments connected individually to the meter body and joined at the bottom by a mercury U tube, the column of which acts in unison with the column of the U tube in the meter body. When a sudden surge of impact pressure occurs, the momentary high differential breaks the safety seal and equalizes the pressure in the two compartments. As the abnormal differential pressure is released, the mercury collects in the U tube, and reestablishes the necessary seal between the two compartments.

Installation of Orifice Plate and Pitot Tube

The orifice plate should be inserted between two flanges, preferably in a horizontal section of the line. In case the flanges connect to a valve or elbow the orifice should be inserted in the flange leading to the fitting.

Where a pitot tube is employed this also should be placed in a length of straight pipe; but if the only available straight pipe immediately follows a bend or valve in the direction of flow, the tube should be attached not

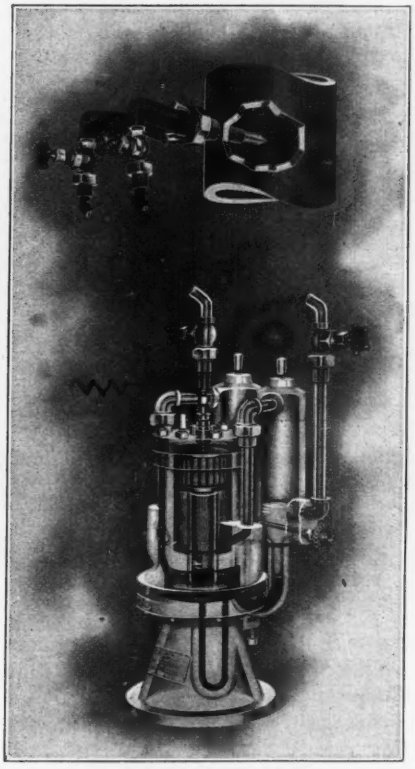


FIG. 9. FLOW METER UTILIZING MERCURY WELL AND ELECTRIC RESISTANCES

less than 3 ft. plus five diameters from the bend. In case there is a bend following the straight pipe, the point of attachment should be at least one pipe diameter ahead of the bend.

Weir Meters

On open or partially open systems weir meters are being extensively used. Rise and fall of the water level above the bottom of the weir is utilized as a measurement of the rate of flow. In the V-notch meter illustrated in Fig. 10 rise and fall of water in the tank provided with the V-notch actuates a float which in turn indicates the height in the notch on the inch scale, Fig. 11. A rack, formed as the float rod, engages a pinion attached to the same shaft as the cam drum upon the surface of which is cut a groove in the form of a screw thread of progressively increasing pitch. This

is the rate-of-flow curve of the notch. Gliding in the groove is a follower, rigidly connected to the slider bar.

As the drum revolves, it moves the pen laterally across the chart, the pen traveling equal distances for equal increments of flow. The integrator is driven by

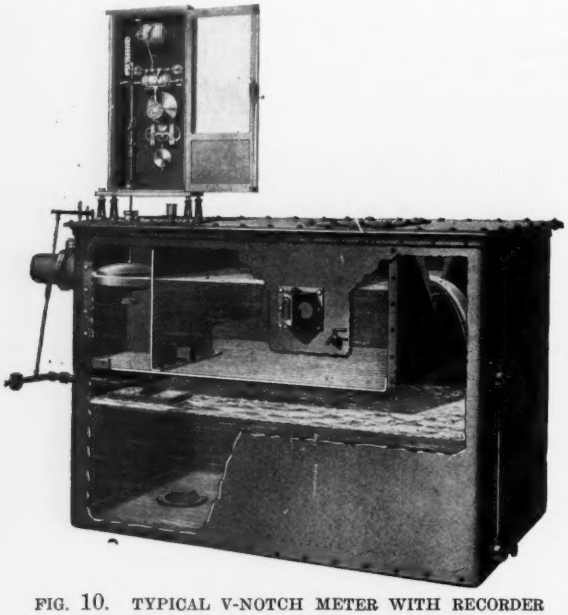


FIG. 10. TYPICAL V-NOTCH METER WITH RECORDER

a separate clock and as the rate of flow is increased it is caused to move from the center of the driving disk and vice versa.

Below the weir chamber, in the extra storage chamber, a float rises and falls with the water level, operat-

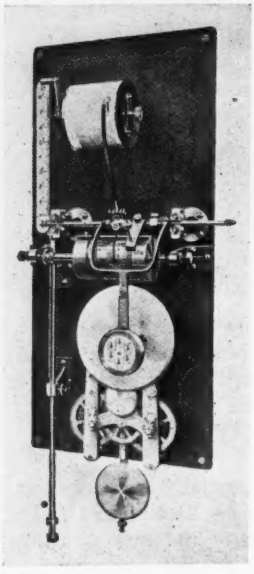


FIG. 11. RECORDING MECHANISM OF METER SHOWN IN FIG. 10

ing a balanced inlet valve which automatically controls the flow of water through the meter to conform with requirements.

An independent method of checking the accuracy of the meter is provided by a little bay window on the side of the tank through which the zero point may be set to an exact level with the bottom or apex of the notch. With this attachment the height of the water flowing through the notch may be measured with a foot rule or, if greater accuracy is required, by means of a hook gage.

This meter uses as its basis of measurement the 90 deg. V notch. For small flows more acute angles allowing flow of ½, ¼ or ⅛ of that of the full 90-deg. notch are employed.

Another meter of the V notch type, but provided with a somewhat different form of recorder-operating mechanism, is that shown in Fig. 12. Water enters the tank at the left end and passes under the still pan and baffle which is made by loosely bolting a U-shaped plate to the inside of the main tank. Within the still pan are two displacing members made of spun copper and hung from the opposite ends of a beam fastened to a Monel metal shaft, supported on knife-edge bearings near its ends and extending through a pressure tight bearing into the recorder case. Although the two displacing

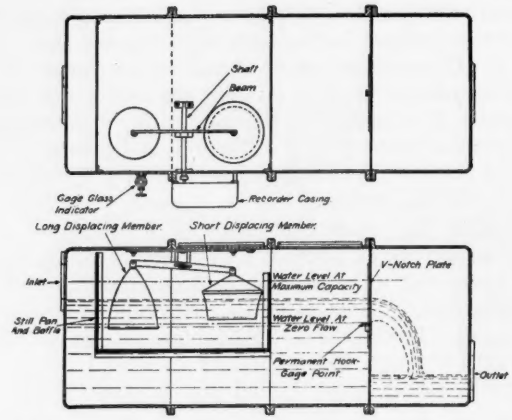


FIG. 12. V-NOTCH METER EMPLOYING TWO DISPLACEMENT MEMBERS FOR OPERATION OF INTEGRATOR

members have equal bottom areas one decreases and the other increases in sectional area toward the top; they are exactly balanced and just touch the surface of the water when it is at the zero level. The relative shape of these members is made in accordance with the flow curve of the V notch so that rotation of the shaft and movement of the recording pen, which is fastened to the extended shaft, are in direct proportion to the rate of flow. As with increased rate of flow the water level rises above the notch the short displacing member rises partly with the water while the long displacing member is pushed deeper into the water to such an extent that the buoyant force of the two is always automatically maintained equal.

The integrator is similar to that used in connection with the flow meter described on page 74; its driving arm projects down from the shaft extension which carries the pen.

In a V-notch meter designed primarily for use in connection with open feed-water heaters and as illustrated in Fig. 13 a float operates the recording and integrating mechanism, the float being placed either in

the still water or approach channel ahead of the weir or in a chamber on the discharge side within which the level of the water corresponds to that ahead of the weir and with which it is in communication. By means of a slender stem and cable attached to the top of the float by a micrometer screw, motion of the float is communicated to a cylindrical drum which with a disk provided with a spiral slot forming a cam is mounted on a spindle resting in bearings.

Horizontal ways support a rolling carriage to which is attached a cam follower, the indicator, the pen holder and the integrator. With zero flow the float is at its lowest point of travel and the cam in a position of no registration. As flow is established due to the rise of

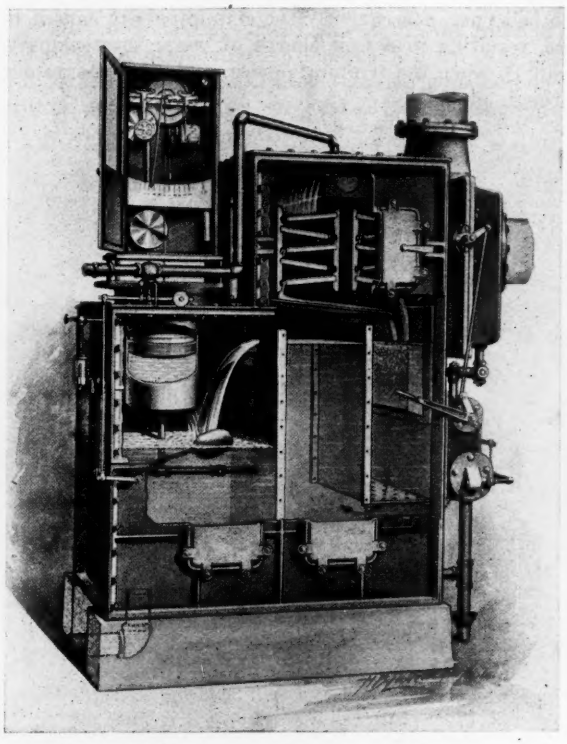


FIG. 13. V-NOTCH METER FOR USE IN CONNECTION WITH FEED WATER HEATERS

the float, the cam disk is caused to revolve and motion imparted to the indicating, recording and integrating mechanisms. The pen holder is pivoted upon the carriage in such a manner that it is held against a paper chart carried by a clock-driven drum while the integrator is driven by a small, light roller held by spring pressure against a large aluminum disk operated by the clock which drives the chart drum.

Adjustment and Care

A locking device is provided for holding the cam disk in either zero or maximum flow position permitting of adjusting the pen and integrator roller to the corresponding position on the chart and on the integrator roller respectively. After this adjustment has been made, the water (at operating temperature) is drawn down to the zero level, as indicated by an auxiliary outside zero pointer placed in a gage glass attached to the weir chamber.

The cam disk is then released and the micrometer adjustment between float stem and cable manipulated until the disk is at zero when controlled by the float. Adjustment in this manner at the working temperature eliminates errors due to expansion, contraction and change in submergence of the float in water at different temperatures.

A weighing vessel suspended by a coil spring and connected to the tank by a flexible bronze hose so that the water in the vessel will be in equilibrium with that behind the weir is the arrangement employed in the meter shown in Fig. 14. As the water rises behind the V-notch it also rises within the weighing vessel and as this contains just enough water to each unit of height to draw down the spring in exact ratio to the rate of flow, the pen and recorder are directly attached to it without the use of cams or other motion-changing devices.

Opposite the recording pen is an arm which supports a small planimeter wheel on a vertical axis and revolved by the clock-driven disk. This wheel moves a train of

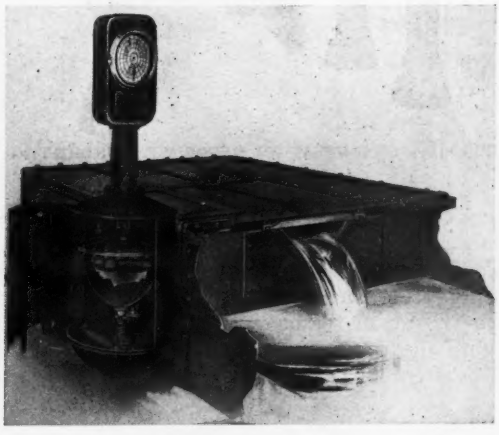


FIG. 14. RECORDING DEVICE OPERATED BY WEIGHING VESSEL

gears operating the integrator which indicates the number of pounds of water passed the weir. With the water just starting over the V-notch the planimeter wheel rests at the center of the disk. As the head increases the wheel is drawn toward the lower periphery of the disk, and as the disk has a constant motion a record is made of the water passing the notch in any given time.

Calibration of V-Notch Meters

By observing the head of water above the apex of the weir the discharg in cubic feet may be determined by multiplying the square root of the value of the head raised to the fifth power, by 3.04.

These meters are generally graduated to read in pounds, in which case there may be an error because of change of density of the water. This error, according to Smallwood, is partly compensated, in that at a higher temperature, for a given head, a lesser weight of water will pass; but on the other hand, the float will stand lower in the hot water, thus making the recording pen indicate less. If the flow were proportional to the head, the correction would be exact.

Volume Measurements

Two devices for the measurement of water by vol-

ume are ilustrated in Figs. 15 and 16. The former which is primarily a condensate meter consists of a cast-iron housing supported by a tripod arrangement of adjustable legs, to which the returns to be measured are piped. The return condensation enters the vapor condensing and equalizing chamber at the top, then discharges into an aluminum dumping bucket, which,

FIG. 15. CONDENSATION METER WITH INDICATING MECHANISM REMOVED

through the medium of a counter, operates an integrator set in a recess in the front of the casing.

Condensate flows through the equalizing chamber to one side of the bucket, which, when filled, overbalances the empty side of the bucket and automatically dumps, bringing the previously empty side under the filling slot, an alternate action accompanied by a movement of

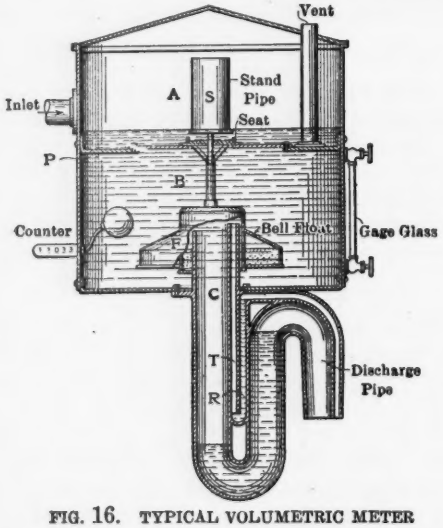


FIG. 16. TYPICAL VOLUMETRIC METER

the counter and the registering dial, graduated to read direct in pounds of condensation passed.

Lugs on each side of the casing projection carrying the integrator allow for the adjustment of the aluminum dumping bucket, the travel of which is limited by means of a bronze shock-absorbing cap slipped over a projection to the bucket shaft.

The meter will give best results on a constant and reasonably uniform flow and preferably float-controlled constant-flow steam traps should be used.

In the device illustrated in Fig. 16 the essential parts are a containing tank divided into two compartments A and B by a partition, P, a standpipe, S, open at top and bottom and having a corrugated bottom face and rigidly connected to a bell float, F, a U-shaped discharge pipe, and a trip pipe, T.

With the standpipe S resting on its seat, water entering through the inlet accumulates in upper compartment A until it reaches the top of the standpipe. Continual entrance of water causes an overflow through the standpipe and into compartment B, until the bottom of bell float F becomes sealed. As flow continues, the bell float, consequently the standpipe, are caused to rise, resulting in a unit charge of water into compartment B, when the tripping device sends this charge out through pipe C.

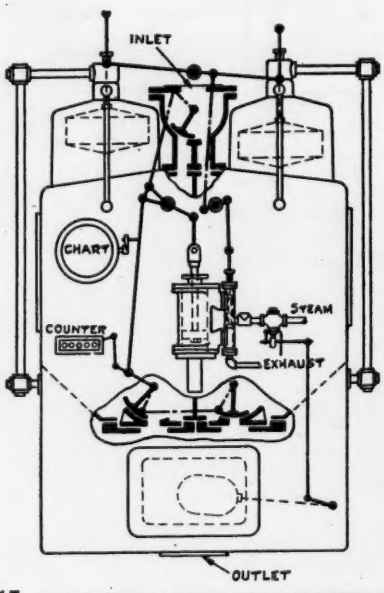


FIG. 17. VOLUMETRIC METER OF PRECISION TYPE

Normally trip pipe T is watersealed; but as the lower compartment becomes filled, the water in the left-hand leg of T is slowly forced downward and part of it caused to overflow into discharge pipe C. With the water level in T lowered to the lower level in the trip pipe, the column in leg R balances the head of water in the lower compartment. Any addition of water to this compartment will then cause an overflow from R and a destruction of the state of equilibrium with the consequence that the air in the bell float and the upper portion of the discharge pipe breaks the water seal in R by suddenly discharging all of the water in it.

With the air removed from under the bell float, the water in compartment B overflows into discharge pipe C, and out through the open end, continuing until a unit charge has passed. Due to the pressure of the water above the float accompanied by the action of the syphon, the float and attached standpipe fall until the latter becomes seated, when water again accumulates in the upper compartment and the cycle is repeated.

The number of times that the lower compartment is

emptied is registered by a counter, and by multiplying the value of each unit charge by the number of times the compartment is emptied within a given time interval the total amount of water passing is readily ascertainable.

Weighers of this type are readily calibrated by weighing several unit charges.

Where considerable accuracy is desired, the volumetric type of meter shown in Fig. 17 is suitable. It consists of two calibrated measuring tanks each fitted at its highest point with a narrow part or chamber in which there is a float, the two floats being connected to a walking beam which operates the valve by which the two measuring tanks are alternately filled and emptied. Each float almost completely fills its chamber, so that the volume of water represented by 1 in. rise around the float is but one one-thousandth of the volume of the metering compartment, thus making it easily possible to secure an accuracy of volumetric measurement within one-half of one per cent. If the temperature and density of the liquid are known, the total liquid handled can be computed with the same degree of accuracy.

Assume the liquid being measured, flowing into the right-hand compartment and out from the left-hand compartment as indicated by the position of the valves. As soon as the water level reaches the float in the right hand compartment, it will shift the piston valve to such a position that communication is opened to the lower end of the cylinder containing the piston which operates both inflow and outflow valves. The piston will not move, however, until the left-hand compartment is empty, allowing the float in the storage compartment to drop sufficiently to admit steam through the throttle valve shown in the steam connection to the valve chest. One of the measuring compartments must be completely full and the other completely empty before the inlet and outlet valves can be reversed.

A counting train connected to the moving parts records the total flow over any given period while the rate of flow can be indicated by the frequency of punch marks made in a clock-driven chart.

Figures 18 and 19 show in principle the construction and mode of operation of a meter designed for boiler feed measurement. Its mechanism consists primarily of a cylindrical copper drum divided into six scroll-shaped compartments, a containing case and an integrator.

Water is admitted by means of a spout introduced axially at the center of the drum, but not connected to it. In the bottom of the spout and extending its entire length is the inlet opening by which the water passes to each compartment successively as the drum rotates.

Starting with compartment 1, directly beneath the spout, the incoming water gradually fills it and the peculiar shape of the compartment causes the greater portion of the water to flow to one side of the perpendicular center line of the drum. By seeking to find the center of gravity, the water turns the drum, until finally, when compartment 1 is full, the weight and location of the water has drawn compartment 2 beneath the spout opening.

This second compartment fills in its turn and draws compartment 3 into place and the water in compartment 1 now begins to overflow at its outer opening in the perimeter of the drum. Compartment 1 does not

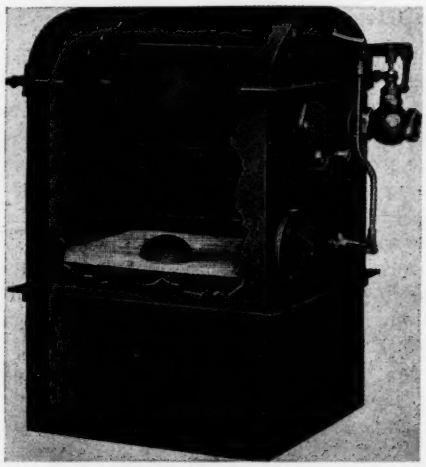


FIG. 18. VOLUMETRIC METER EMPLOYED FOR MEASUREMENT OF BOILER FEED

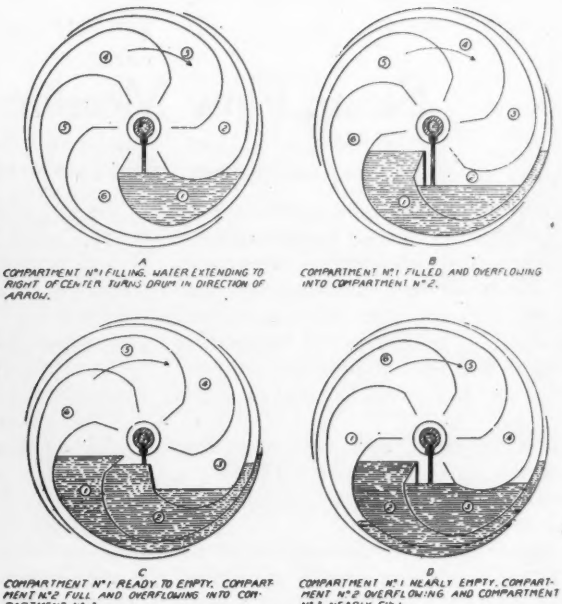

A
COMPARTMENT N°1 FILLING. WATER EXTENDING TO RIGHT OF CENTER. TURNS DRUM IN DIRECTION OF ARROW.
B
COMPARTMENT N°1 FILLED AND OVERFLOWING INTO COMPARTMENT N°2.
C
COMPARTMENT N°1 READY TO EMPTY. COMPARTMENT N°2 FULL AND OVERFLOWING INTO COMPARTMENT N°3
D
COMPARTMENT N°1 NEARLY EMPTY. COMPARTMENT N°2 OVERFLOWING AND COMPARTMENT N°3 NEARLY FULL

FIG. 19. ILLUSTRATING MECHANISM OF METER SHOWN IN FIG. 18

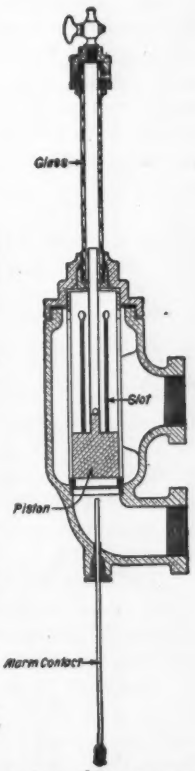


FIG. 20. METER FOR LOW RATES OF FLOW

commence to discharge until compartment 3 is partly filled.

Shape of the compartments is such as to prevent any surge in the water and consequently motion of the drum is steady and continuous and, as any compartment cannot fill and discharge at the same time, any change in the volume or force of the incoming water, which might cause surging, cannot affect the discharge and consequently cannot change the accuracy of the meter.

All compartments are alike and, as each receives and discharges the same volume of water at each revolution, it necessarily follows that the quantity of water passing through the drum at each revolution must always be the same.

Whether the water is delivered to the meter in large or small quantities, it cannot change the accuracy, for the impact or impulse of the water does not affect its rotation. If the water is suddenly stopped the motion of the drum also stops and the water already in it remains stationary until such a time as enough more is admitted to change its position and cause the second preceding compartment to discharge.

For water and oil flow not in excess of 50 gal. per minute, the meter illustrated in Fig. 20 may be employed to advantage. It consists of a cylindrical chamber with suitable pipe connections enclosing a slotted tube through which the liquid must pass. Inside of this tube is a piston which moves up and down, exposing a slot area sufficient to allow any flow of liquid within the capacity limits of the instrument. Movement of the piston indicates on a graduated scale the amount of flow in gallons per minute which is directly proportional to the area of the slots in the enclosed tube or to the rise or fall of the piston.

An electric contact consisting of an adjustable insulated brass rod located at the bottom of the chamber can be connected to a lamp or bell, calling attention when the flow has fallen below a fixed minimum. Contact is established immediately when the piston rests on the brass rod. Adjustment is made by loosening the insulated gland nut through which the contact rod extends, and moving the rod and piston to the index position on the meter scale corresponding to the required capacity. The gland nut may then be tightened to retain the contact rod in this position.

Steam Flow Measurements

INSTRUMENTS USED FOR THE PURPOSE; THEIR CONSTRUCTION, INSTALLATION AND CARE

MOST of the water-flow meters employing the U tube and mercury column may be used for the measurement of steam flow, for which service, however, it is necessary to utilize some form of condenser to avoid bringing the steam into direct contact with the internal mechanism. An indicating, recording and integrating instrument of this type and one adapted not only for the measurement of steam and water, but also of air, is shown in Fig. 1.

The body of the meter consists of an iron casting cored so as to form the leg and well of a U tube; a bypass valve is provided at the side of the instrument to equalize the pressure of the system.

Attached to a float resting on the surface of the mercury in the leg of the U tube is a circular rack which engages a pinion mounted on a shaft carrying a large horse shoe magnet with pole faces near a copper plug bolted on the body casting. Another magnet, also horseshoe in shape, is mounted with its pole faces near the same copper plug and with its axis of rotation in alinement with the shaft carrying the horse-shoe magnet inside the meter body. A pinion on the shaft carrying the outside magnets engages a sector to the shaft of which is attached the recording pen. The clock driving the recording chart is mounted in front of the magnet, pinion and sector and may be of a type to provide a chart speed of one revolution in one hour, one revolution in 8 hr., in 12 hr. or in 24 hr.

Difference of pressure in the flow nozzle, orifice tube or Pitot tube, any one of which may be employed according to capacity of the instrument, is transmitted to the U-tube system of the meter and causes the mercury in the well to rise into the leg of the U-tube containing the float. The height of the mercury in this leg is proportioned to the differential pressure produced.

By means of the float and rack the pinion carrying the magnet inside the body is rotated in proportion to the change of load of the mercury. Any motion of this magnet is transmitted magnetically to the outside magnet carrying the pinion which engages with the large gear sector driving the recording pen causing it to deflect in proportion to the change of mercury level in the leg of the U-tube containing the float.

The integrating device which automatically integrates the values of flow recorded on the chart, is provided with a locking attachment which prevents readings being changed when charts are being replaced.

For permanent installation the indicating scale of this instrument may be calibrated in either pounds steam per hour or boiler horsepower while the chart is calibrated in arbitrary units from 0 to 10 and a multiplying constant used to reduce the readings to values representing the flow in pounds per hour or boiler horsepower.

Boiler horsepower calibrations are based upon an equivalent of 30 lb. of steam per hour.

The meter may be located in any convenient place not subject to severe vibration and where it can be protected from damage and from freezing. The instrument may be installed either above or below the flow nozzle although the horizontal piping between the reservoir and meter should slope toward the meter to prevent pocketing.

Flow nozzles having the necessary static and dynamic openings may be installed in horizontal, vertical or inclined pipe lines but sufficient space must be allowed for the piping, the reservoirs and valves. Gaskets should be placed on each side of the flange, care being taken, however, to have that on the upstream side not extending inside of the pipe.

The pipe carrying the flow nozzle should have a straight run of at least six pipe diameters preceding the leading side of the nozzle; that is, if the inside pipe diameter should be, let us say, 6 in., the pipe should be straight for at least 36 in.

Desirable locations of flow nozzles are as shown in Fig. 3.

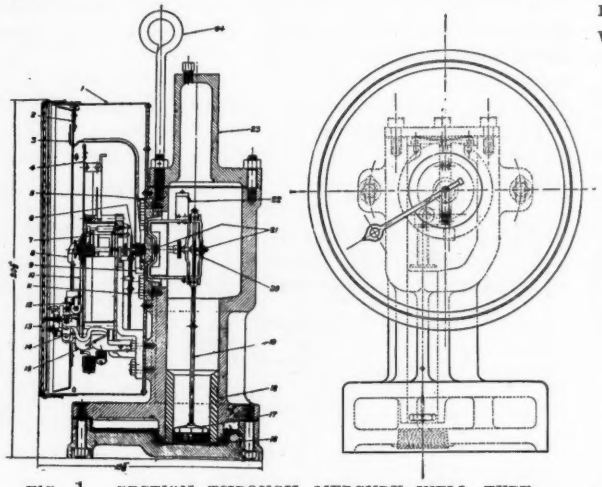


FIG. 1. SECTION THROUGH MERCURY WELL TYPE STEAM-FLOW METER

Steam flow meters employing the Pitot tube principle are shown in Figs. 4 and 5. That in Fig. 4 consists of an ordinary water gage with proper fittings attached to the steam line and with the gage in connection with dynamic tube D and static nozzle S. In describing the operation of these instruments Gebhardt states that the height of

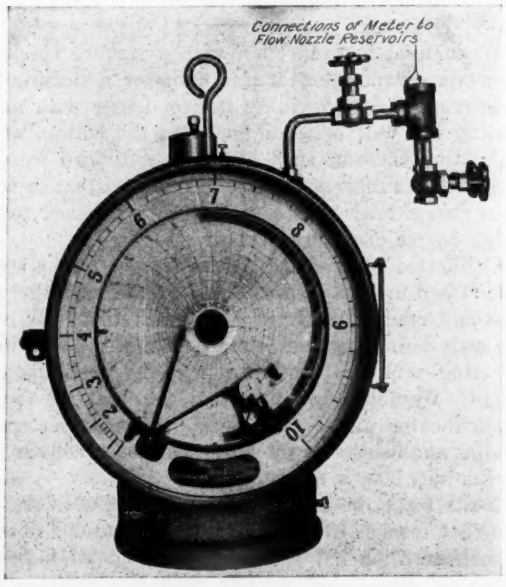


FIG. 2. INTEGRATING METER OF TYPE SHOWN IN FIG. 1

water H is proportional to the square of the velocity of the steam flowing through the pipe and automatically adjusts itself to the variations in velocity; thus for decreasing velocities the water in the glass discharges through D until column H balances the velocity pressure in pipe P, and for increasing velocities condensation from the upper part of the instrument accumulates and the water column H rises until a balance is effected for the higher velocities. Provided with the proper form of scale, this instrument may be made to read directly in pounds per hour.

Figure 5 shows another form of instrument which may be below or above the point in the main pipe at which the Pitot tubes are placed. Velocity pressure is

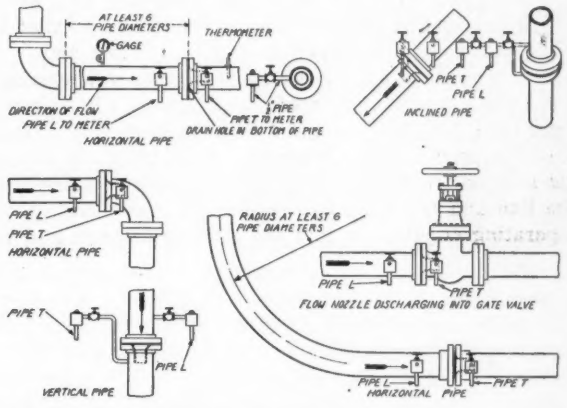


FIG. 3. DESIRABLE LOCATIONS OF FLOW NOZZLES FOR METERS ILLUSTRATED IN FIGS. 1 AND 2

transmitted through tube D and opening O into the body of chamber M. This pressure, acting on the surface of the condensed steam in the chamber forces the water into glass W until a balance is effected. Condensation is discharged continuously through pipe P and water seal U of the main pipe.

Due to the form of design employed the steam flow meter illustrated in Fig. 6, requires connection directly

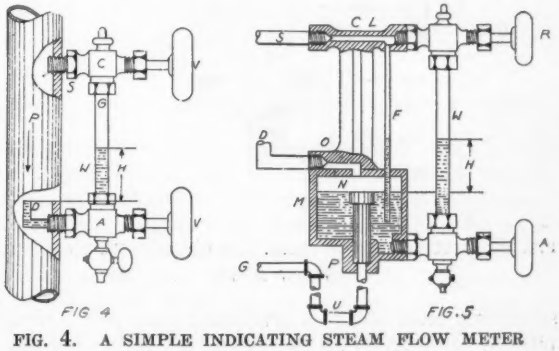


FIG. 4. A SIMPLE INDICATING STEAM FLOW METER

FIG. 5. INDICATING STEAM FLOW METER WITH CONDENSATION CHAMBER

in the main through which the steam to be measured passes. When the pressure of the steam entering A exceeds that in chamber B by 2 lb., brass valve V is raised from its seat, the degree of rise depending upon the volume of steam flowing. Movement of the valve is transmitted through an arm carried by a horizontal shaft projecting through the casing and carrying at its outer extremity the recording pencil and indicator pointer.

THE Co_2 METHOD OF STEAM MEASUREMENT

THIS METHOD, which is based upon the addition of

CO_2 gas from a high pressure drum to the steam line at a continuous and known rate, is entirely independent of pressure, superheat, or per cent of moisture and requires no pipe changes except for the drilling and tapping of 2 ⅛-in. holes. It is particularly adapted for test work in calibrating meters and determining steam consumption of turbines, engines, pumps, etc., although it is not intended to take the place of a permanently installed recording or integrating instrument.

Referring to Fig. 7 the drum containing CO_2 under high pressure is supported on a scale beam so that its weight can be determined at any time, from which, in turn, the rate of adding the gas is accurately determined. The gas is continuously discharged through a flexible copper tube, governor valve and into the steam line through a ⅛-in. spray tube. A sample of the mixed steam and gas is taken from the steam pipe at a point farther down the line and is then passed through a condensing and separating apparatus and the condensed steam and gas

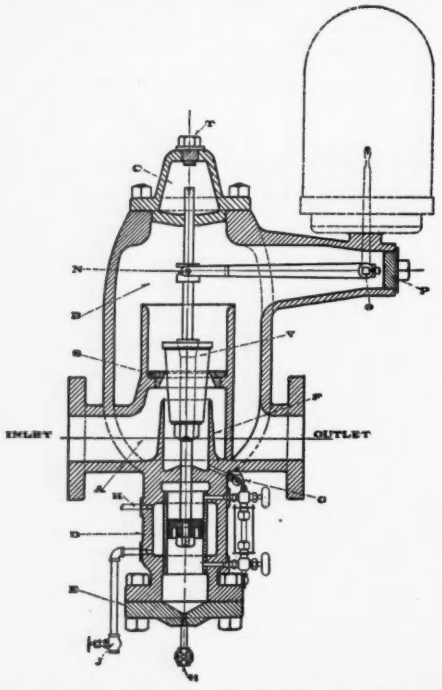


FIG. 6. MECHANISM OF VARIABLE ORIFICE TYPE OF STEAM FLOW METER

separately measured in a graduated glass and a Hempel burette respectively to determine the ratio of water to gas. This ratio multiplied by the rate at which the gas was added will give the rate of flow of steam.

An accuracy of from 1 to 1.5 per cent can be secured when using only 1 lb. of gas to 2000 lb. of steam. Hence it is possible to use this method on capacities up to several thousand pounds of steam per hour.

This method is also applicable for the measurement of flow of water, the gas being injected into the feed line. With the small ratio required, the CO_2 is completely absorbed by the water so that a representative sample is readily obtained. The gas is then completely separated from the water and the ratio obtained by the measurement of each.

Calibration of Steam-Flow Meters

Steam flow meters may be best checked for accuracy by means of the CO_2 method of measurement, by comparison with a standard instrument known to be correct or by direct weighing of the condensed steam. If the last named method is employed, the steam passing through the meter is discharged into a surface condenser and the condensate formed weighed in a tank placed upon platform scales.

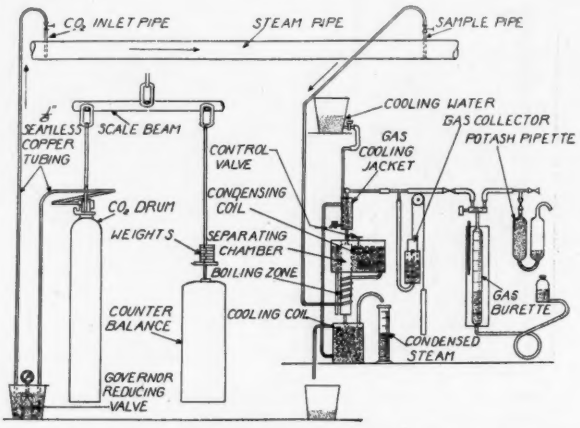


FIG. 7. DIAGRAMMATIC LAYOUT OF CO_2 METHOD OF STEAM MEASUREMENT

Care must be taken to insure employing saturated steam and as a means of checking the quality it is advisable to use a throttling calorimeter. The maintenance of a constant flow of steam during each of a number of runs at different rates is desirable.

When used in connection with a surface condenser the steam consumption of an engine or a turbine may be determined by providing the condenser with an indicating hot well bolted directly to the bottom of the shell. One make of such hot well is divided into two compartments separated by a wall or partition in which is inserted a brass orifice finished and polished to give a high degree of accuracy.

Calibrated by an independent factory test, a special scale etched upon steel is attached to the indicating gage glass and reads directly in pounds of steam per hour., this scale indicating the height of the condensate in the collecting well, or in other words, the head upon the orifice. By taking simultaneous readings of the hot well indicator and an indicating kilowatt meter and dividing the former by the latter, the steam consumption per kilowatt hour is obtained.

Tests made on a 5000-kw. turbo-generator set indicate that from half load to full load readings obtained by means of the hot well indicator and an indicating wattmeter correspond exactly with the readings of a high-grade steam-flow meter. From no load to half load the error was less than 5 per cent.

There is a principle which is a bar against all information and which will keep a man in everlasting ignorance; that principle is contempt prior to investigation. —Graphite.

Air Flow Meters

Instruments and Means of Determining Rate of Flow

WHILE most of the water and steam flow meters employing the mercury column or U tube in conjunction with the orifice or Pitot tube are with little or no modification applicable to the measurement of air flow, local conditions or service requirements may favor the use of some other type of instrument. A meter designed to measure and indicate the number of cubic feet of free air per minute output of air compressors, and for the measurement of high-pressure air in general, is shown in section in Fig. 1.

The moving element consists of a weighted piston in the upper or metering cylinder, a small piston in the oil dashpot cylinder and a rod joining the two pistons

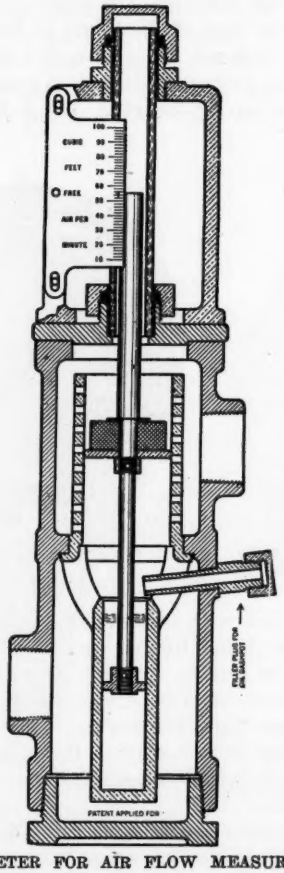


FIG. 1. METER FOR AIR FLOW MEASUREMENT

and extending upward where it moves freely, without contact, inside the sight glass at the top of the meter. This rod rises and falls with the pistons so that its height in the sight glass corresponds to the position of the piston in the metering cylinder. The scale plate mounted against the outside of the sight glass permits reading the exact height of the top end of the rod.

Air enters at the lower left-hand opening into the chamber surrounding the dashpot cylinder and passes through ported openings into the interior of the metering cylinder, the wall of which is drilled with a large number of small, accurately reamed holes uniformly spaced. To pass to the outlet chamber, the air lifts the piston and exposes some of the holes to the flow.

A small "head," or difference of pressure, is established between the interior of the cylinder and the outlet chamber; this pressure difference, only a few ounces per square inch, being fixed by the exact weight of the moving element and the area of the piston on which the difference of pressure acts. The moving element rises until the weight is exactly supported by the difference in pressure; the pistons and rod are then floating in static balance in a position corresponding exactly to the volume of air flowing, the number of holes exposed and the height of the top of the rod in sight glass. The divisions of the scale plate are calibrated by comparison with a standardized instrument.

For air velocities not exceeding 2000 ft. per minute, the anemometer is well suited. This device consists of a light vane attached to a shaft carrying a counting mechanism, and in operation the meter is so held as to bring the shaft parallel to the direction of flow of the air.

A more accurate instrument is the so-called wet-gas meter shown diagrammatically in Fig. 2. Each of the four compartments, A, B, C and D, is provided with a

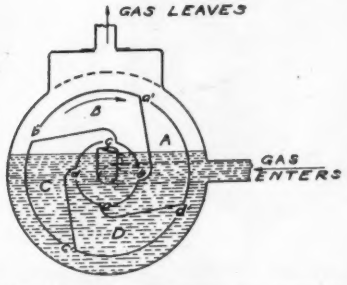


FIG. 2. DIAGRAMMATIC SECTION OF WET-GAS METER

passage such as a, b, c and d at the center and a′, b′, c′ and d′ along the periphery. Gas enters through the connection at the right, passes through a center aperture and into the compartment above the water level as at C, causing this to fill and thereby turn the revolving member on its axis. This continues until opening c′ leaves the water when the gas in C escapes. Opening d is then in such position as to admit gas to D when the cycle is repeated.

For high-pressure work, Moyer suggests the use of the receiver method of air measurement, the air from a cylinder being pumped into a strong receiver, the pressure maintained constant by a regulating valve on the discharge pipe. Observations are made of the absolute initial and final pressure in pounds per square inch and represented by P_1 and P_2 respectively; the mean absolute initial and final temperature T_1 and T_2 deg. F.; and the initial and final weights of air in the receiver, W_1 and W_2 lb. respectively. V is the volume of the receiver in cubic feet. Then, as P_1V is equal to W_1RT_1 and P_2V is equal to W_2RT_2 where R has a constant value of 53.3 for air, the weight of air pumped is equal to $W_2—W_1$, or $(V \div 53.3) \times (P_2 \div T_2)$ minus $(P_1 \div T_1)$.

Pressure and Vacuum Gages

Indicating and Recording Instruments; Calibrating Devices

FOR PURPOSE of indicating pressures, three general types of gages are employed, the Bourdon type, the diaphragm type and the manometer or U tube. Gages of the Bourdon and diaphragm types consist of two essential parts, the pressure element and the movement.

In gages of the Bourdon type, pressure is applied internally to an elastic hollow brass or steel tube of oval section, bent into the shape of a circular arc and closed at one end. Since the closed end of the tube is free to move, while the other end is fixed, fluid pressure on the inside tends to increase the short diameter of the section, causing the radius of curvature of the whole tube to become larger, thus moving the free end a distance proportional to the pressure applied. By connecting a suitable multiplying mechanism to the end of the tube a needle or pointer may be moved so as to indicate on a graduated dial the pressure in the units desired.

In the diaphragm gage, the indicating device is actuated by a corrugated metal disk or diaphragm, clamped around its edges by the flange of an encircling chamber. The deflection of the diaphragm is proportional to the pressure applied to its lower side, and its movement is communicated to the pointer by a mechanism similar to that used in the Bourdon type.

Manometers, or U-tubes, which consist merely of a glass tube bent into a U-shape, and partly filled with a liquid such as mercury or water, are simple and sensitive instruments for measuring pressure or vacuum, as they have no working parts to become deranged. If one branch of the tube is connected to the source of pressure and the other end left open to the atmosphere, the difference in level of the liquid in the 2 branches of the tube will indicate, on a properly graduated scale, the pressure or vacuum in inches of mercury, water, or whatever unit may be desired. The U-tube is suitable,

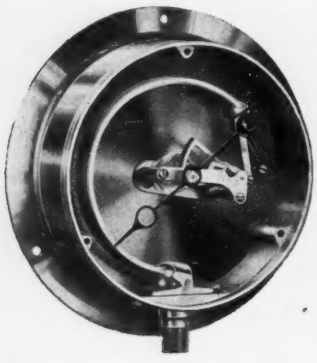


FIG. 1. INTERIOR VIEW OF BOURDON TYPE OF PRESSURE GAGE

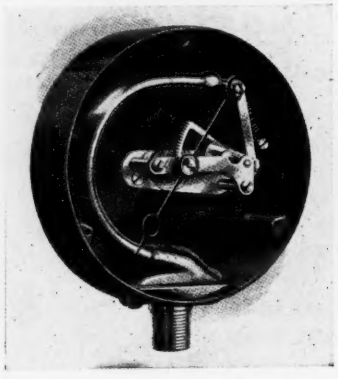


FIG. 2. INTERIOR VIEW OF AUXILIARY SPRING GAGE

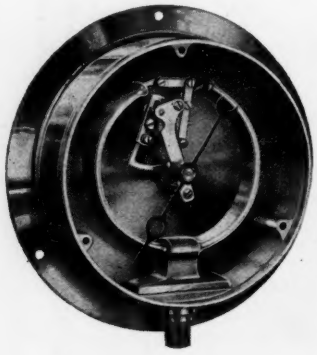


FIG. 3. SHOWING CONSTRUCTION OF DOUBLE TUBE GAGE

Generally the multiplying mechanism is made up of one or more levers, a toothed segment or sector, a pinion and a hair spring. Adjustment of the ratio of movement between the pointer and the end of the tube is made by either a slotted sector rim or a connecting link, the length of which may readily be changed to suit conditions. Lost motion of the parts is taken up by the hair spring attached to the spindle carrying the pointer.

Owing to pointer vibration due to jarring which occurs in certain classes of service, also the rapid fluctuations of pressure sometimes encountered, double-spring gages are frequently employed. The pressure tubes in such gage may consist of two separate branches or may be continuous; but in either case, there are two free ends, which, when properly connected by a lever mechanism, give a greater pointer movement than is obtained with a single spring.

In Fig. 2 is shown an auxiliary spring gage, the function of the auxiliary coil spring being to return the free end of the tube to its original position when the pressure is removed thus offsetting any tendency toward a permanent set, and to minimize the whipping of the free end of the gage tube under excessive vibration.

even when filled with mercury, only for comparatively low pressures, being limited by the inconvenience due to its length or height.

For the measurement of vacuum, both the Bourdon and diaphragm types are commonly used, the design of the gage being altered only in the arrangement of the levers to accommodate the reversed movement of the tube or diaphragm.

Bourdon gages can be used for indicating pressures of liquids, steam or gases, where the tube does not reach a temperature much in excess of 150 deg. F., as above this limit the temper of the tube is likely to be affected. When used for steam pressures, therefore, a siphon must always be employed to prevent steam coming into contact with the tube, and should be of sufficient capacity to fill the gage tube with water.

Various gages of the Bourdon type are manufactured, the chief differences being in the details of construction. The distinctive features are the material and mounting of the tubes and movement, and the smooth action of the gearing. The movement may be mounted on the back of the gage, or on the gage socket, the claim for the latter construction being that it removes liability of the move-

ment being thrown out of adjustment while the gage is being screwed into position, and of overheating of the tube, on account of the air space surrounding it. To secure and maintain the greatest possible accuracy, the tubing should be properly selected and seasoned to remove all natural set, and the gearing should be precisely cut. Also the moving parts should be free, so far as possible, from wear and friction, non-corrodible material being generally used.

As in the case of indicating instruments recording pressure gages may also be of the Bourdon tube, the diaphragm or the manometer type.

Calibrating Pressure Gages

Gages may be checked for accuracy and calibrated by means either of comparison with a standard gage or the use of a dead-weight testing device, such as shown in Fig. 6. This tester consists of a stand from which rises a cylinder, having accurately fitted into it a piston with an area of 1.5 sq. in. which moves freely up and down. Attached to the top of the rod is a disk for the support of the weights; each weight is marked with the number of pounds pressure per square inch that it will exert on the gage. From the bottom of the cylinder, two tubes project; one from a standard for holding the gage to be tested while the other, inclined, serves as a reservoir for oil and is fitted with a screw plunger.

After the gage under test is attached and the three-way cock placed horizontally, the reservoir is filled with oil. This is done by turning the plunger inward to the extreme of its travel and pouring oil into the cylinder until filled; the plunger is then gradually withdrawn and at the same time more oil is added, continuing this until the plunger is in its outer position and with the cylinder nearly full.

The nozzle under the cock is opened and the piston inserted, which with its disk will indicate a pressure of about 5 lb. on the gage. The weights, one at a time, may now be placed on the disk which should be gently rotated to insure perfect freedom of motion to the piston. Each weight added will indicate a pressure on the gage equal to the number of pounds marked on it, and if the reading of the gage does not correspond to the total number of weights added, corrections of readings will have to be made for the error.

If, in testing a large gage, the piston descends to its full length screwing in the plunger will force it upward, thus allowing the addition of more weight as may be required.

For the calibration of vacuum gages, the device illustrated in Fig. 7 is applicable. This consists of a hand-operated vacuum pump and a mercurial vacuum gage for checking the readings of the gage under test.

By means of the pump the air is exhausted and the reading of the gage compared with that of the mercury column.

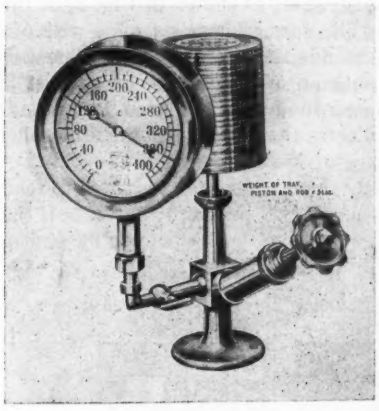


FIG. 6. TYPICAL DEAD WEIGHT GAGE TESTER

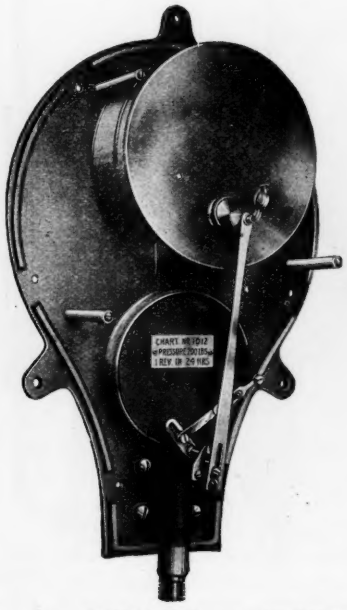


FIG. 4. MECHANISM OF RECORDING GAGE EMPLOYING BOURDON TUBE

FIG. 5. MECHANISM OF RECORDING GAGE EMPLOYING DIAPHRAGM

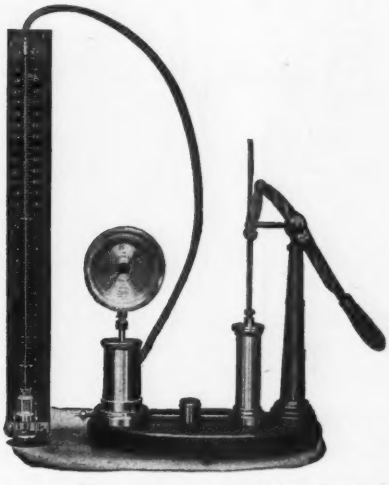


FIG. 7. DEVICE FOR CALIBRATING VACUUM GAGES

Barometers and Vacuum Measuring Instruments

DESCRIPTIONS OF VARIOUS TYPES, THEIR CONSTRUCTION AND PRINCIPLES OF OPERATION

BAROMETERS may be of either the mercury-tube type, Fig. 1, or, as shown in Fig. 2, of the aneroid type. The former consists of a well of mercury into which extends the open end of a glass tube devoid of air and with an overall length of at least 30 in. A scale graduated in inches is placed to one side of this tube and indicates the pressure of the atmosphere acting on the surface of the mercury.

Frequently these scales are graduated to read directly in pounds atmospheric pressure; but if not, the reading in inches may be converted to pounds by multiplying by 0.491 or dividing by 2.035.

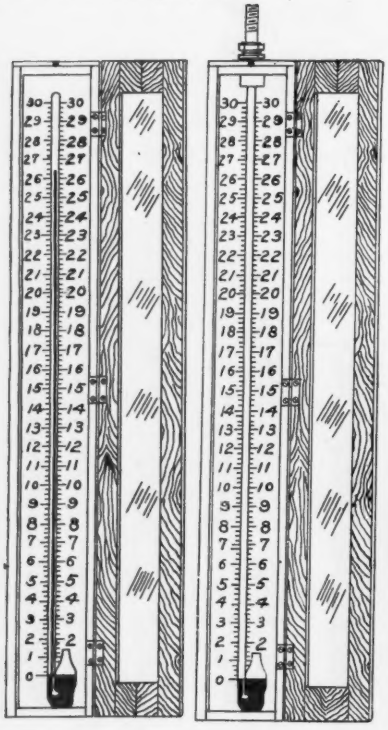


FIG. 1. BAROMETER OF THE MERCURY-TUBE TYPE

FIG. 3. VACUUM GAGE OF MERCURY-TUBE TYPE

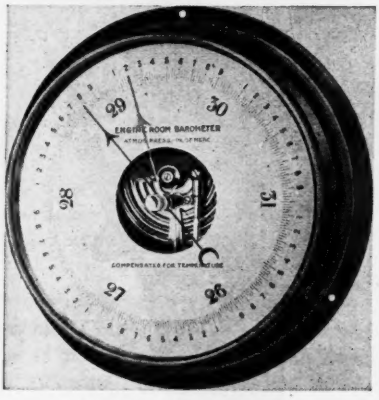


FIG. 2. ANEROID ENGINE ROOM BAROMETER

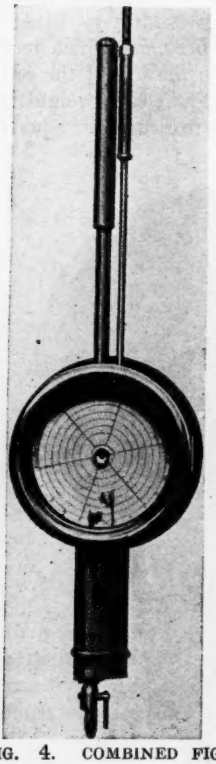


FIG. 4. COMBINED BAROMETER AND VACUUM RECORDER

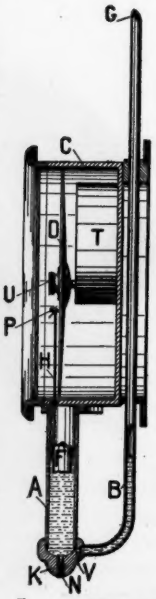


FIG. 5. VACUUM RECORDER OF MERCURY FLOAT TYPE

The aneroid barometer is a more sensitive and more accurate instrument than the mercury column and, due to its portability, is more readily adapted to power plant work. In this instrument, which must be frequently calibrated by comparison with a mercury barometer, a cylindrical metal box with a back of some thin corrugated elastic metal is employed. When the air is removed from this box, any increase of atmospheric pressure acts on the back and forces it inward, while, with a decrease of atmospheric pressure, the back moves outward, due to its elasticity and the assistance of a spring. Motion is communicated by means of multiplying levers to a pointer moving across the face of a graduated scale.

Vacuum Gages

THE MERCURY TUBE may be used as in the form shown in Fig. 3. as a vacuum gage. One leg is comparatively short but correspondingly large in diameter, while the other or longer leg is open and in communication with the vacuum being measured. The instrument may be adjusted to indicate the number of inches of mercury or inches of absolute pressure by bringing the level of the mercury to the zero of the scale. Care must be taken to read at the top of the meniscus, or curved surface of the mercury.

Due to temperature variations, changes will occur in the density of the mercury and the degree of expansion of the scale. For the former, subtract from the reading 0.000,101 h (t — 32) and for the latter add 0.000,010,5 h (t — 32) where h is the observed height of the mercury column in inches read on a brass scale at t deg. F.

To correct for latitude and elevation, multiply the height of the mercury column by (1 — 0.0026 cos 2a — 0.000,000 2H), a being the degrees latitude and H the elevation of the barometer above sea level, expressed in meters.

A combined barometer and vacuum recorder is illustrated in Fig. 4. It consists of two float chambers in a single casing, one connected with a barometric mercury

column and the other with a mercury column in communication with the condenser. The pens are actuated by the floats resting on the mercury in the float chambers and move according to the barometric pressure and vacuum.

Section through a vacuum recorder is shown in Fig. 5. The smaller leg of the U tube connects with the source of vacuum; the larger contains a float which actuates the recording pen.

Draft Gages

Draft gages measure static pressures or difference of pressure and are of the following types: The diaphragm construction, which indicates or records the draft; an ordinary glass U tube manometer filled with water; and the float type, such as shown in section in Fig 7. This consists of a case C containing clockwork T driving chart holder E. Directly below this case is mounted a cylindrical vessel A containing oil. Concentric with this vessel is tube M containing mercury. Bell B, which is sealed by oil O, is buoyed

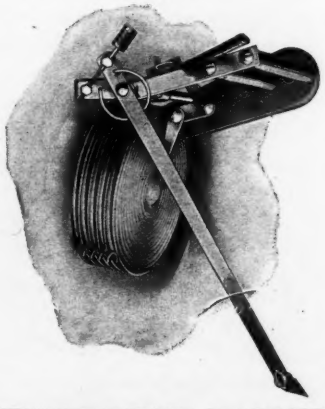


FIG. 6. ACTUATING ELEMENT OF LOW-PRESSURE DIAPHRAGM TYPE GAGE

up by float F attached to stem S and immersed in the mercury. Pen P is supported and moved directly by the bell by means of elastic arm R.

With suction or draft applied to G, the bell descends until it is balanced by the mercury displaced during the descending of stem S, the diameter of which is so proportioned as to give the desired range.

Two bells hung from opposite ends of a beam pivoted in the middle on knife edge bearings are employed in the differential recording instrument shown in Fig. 8. When a pressure less than atmospheric is to be recorded, connection should be made at L, and for a pressure in excess of atmospheric, connection should be made at H (the other connection being left open in both cases). For measuring the differential of two pressures, the higher pressure of the two should be connected at H and the lower at L, this regardless of whether the pressures are above or below atmospheric.

If a slight suction pressure is applied to connection L, it is effective over the inside area of the bell and acts the same as if on a piston of like area, pulling the bell down into the liquid; the right-hand bell becomes lighter and the left-hand bell heavier, due to the buoyant action of the liquid on the walls of the bells, and this force due to buoyancy balances the force caused by the pressure. Amount of motion is directly proportional to the pressure or pressure difference.

There is also another type of draft gage which combines the U tube and the inclined tube. This may be of the single, double or triple tube types. When of the double it is known as the duplex gage, and when triple, triplex.

For accuracy and sensitiveness, as in boiler tests, the inclined tube is especially adapted, as it shows minute variations. This type of instrument consists of the inclined tube with an enlarged chamber at its lower end,

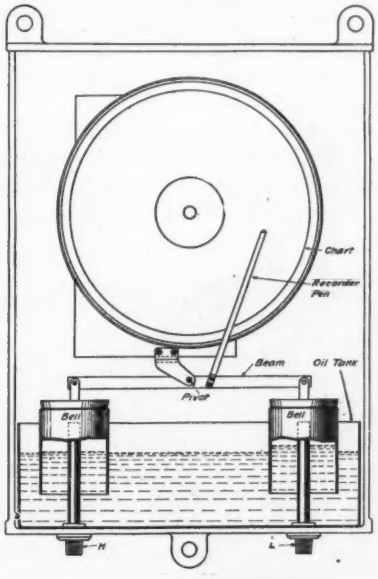


FIG. 8. SHOWING CONSTRUCTION OF DIFFERENTIAL RECORDER

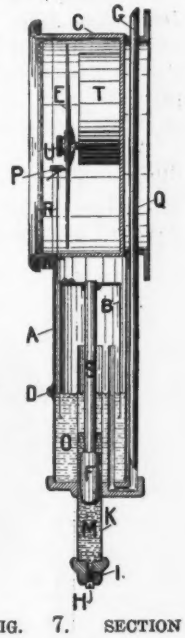


FIG. 7. SECTION THROUGH DRAFT RECORDER

a scale graduated to read in 0.01 in. of water, and a light metal frame or case to which is attached a small leveling glass.

To be accurate, it is essential that the bores of the inclined tube and enlarged chamber be uniform; that is, the ratio of their internal areas must remain constant throughout the ranges traveled by the liquid.

Special mineral oil is best for the liquid, as it has less capillarity, is lighter, permitting a wider range, and

FIG. 10. DRAFT TUBE OF INCLINED-TUBE DIFFERENTIAL TYPE

is less volatile than water. The inclination of the tube is ordinarily about 10 to 1 and is so adjusted that the air bubbles in the level stand central between the two lines; then the indicating liquid is poured into the chamber of the glass to zero on the scale, from which point all readings are taken.

Temperature Measuring Instruments

THERMOMETERS AND PYROMETERS

THREE TYPES of mercury thermometers are in general use, the ordinary instrument which employs a vacuum above the mercury and has a temperature range of from—38 to 575 deg. F., the Jena glass type containing nitrogen above the mercury and the Quartz glass type also utilizing nitrogen. Temperatures of from —38 to 1000 deg. F. may be measured by means of the Jena glass type, while the Quartz glass thermometer employed primarily for special work is capable of withstanding temperatures up to 1500 deg. F. For low-temperature work, alcohol or petrol ether thermometers are especially applicable.

Where cups or wells are employed, these should be filled with cylinder oil or mercury and the thermometer kept from contact with the walls by means of waste wrapped around the bulb or a cork slipped over it.

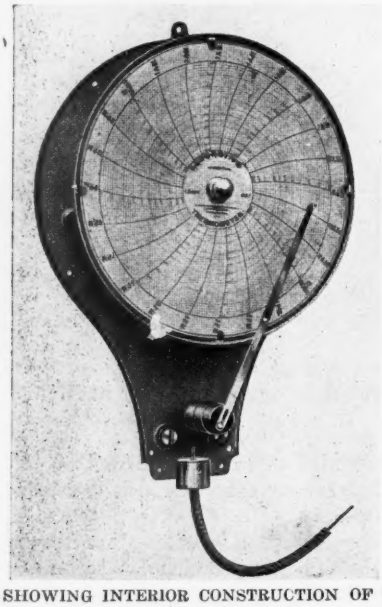


FIG. 1. SHOWING INTERIOR CONSTRUCTION OF TYPICAL RECORDING THERMOMETER

As ordinarily employed, thermometer stems are subject to considerable radiation and, as a consequence, allowance must be made for the resulting loss by the addition to the reading of a "stem exposure" correction factor. This is equal to the product of 0.000,088, the number of degrees of scale exposed and the difference between the observed reading and the reading of an auxiliary thermometer having its bulb about 4 in. from and on a level with the midpoint of the exposed stem.

The recording thermometer illustrated in Fig. 1 depends for its operation upon the pressure due to the expansion of a gas contained within a sensitive bulb connected to the instrument by a small flexible copper tube 25 ft. or more in length. The varying pressures due to the expansion of the gas in the bulb are proportional to the changes in temperature and are transmitted to the recording mechanism by the tube.

Vapors of mercury, ether or other liquid are used in these instruments. For a temperature range of from 15 to 200 deg. F., sulphur dioxide is used; for from 95 to 250 deg., ether; for from 212 to 450 deg., water; 410 to 700 deg. F., heavy hydro-carbons and for temperatures of from 650 to 1350 deg. F., mercury.

With thermometers of this type it is imperative that the entire bulb be subjected to the temperature being measured.

Electricity is the agent employed in electric resistance and thermo-electric thermometers and pyrometers. The former depend for their operation upon the variation in electrical resistance of certain metals with increase in temperature and are particularly well suited for temperature ranges of from—400 to 2200 deg. F. Such a thermometer consists of a coil of pure annealed platinum wire wound upon a framework of mica, a wheatstone bridge and a galvanometer the scale of which is graduated in degrees of temperature. The junction of the platinum wire with the wires leading to the resistance measuring device must be placed in the cooler portion of the circuit where the temperature should correspond to that at which the instrument was calibrated. When this condition is not attainable, compensators are used.

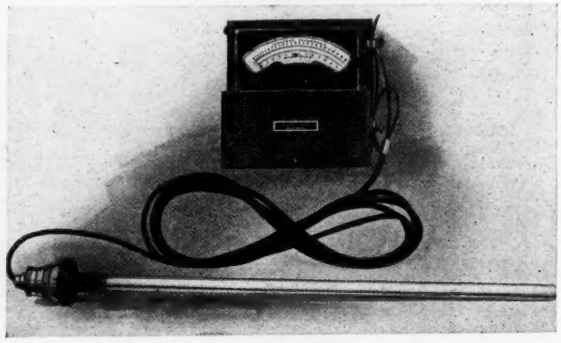


FIG. 2. PLATINUM-RHODIUM THERMOCOUPLE AND INDICATING INSTRUMENT

For working ranges up to 3500 deg. F., the pyrometer which operates upon the thermo-electric principle and as shown in Fig. 2 is useful. Temperature measurement is accomplished by means of an electric current generated in a thermo-couple made by joining dissimilar metals, those used for work up to 1500 deg. F. generally being nickel for the positive element and an alloy of nickel and chronium for the negative. Higher-temperature couples are made up of one wire of pure platinum and another of 90 per cent platinum and 10 per cent rhodium. A sensitive galvanometer or voltmeter, usually graduated in degrees of temperature, measures the voltage which varies as the temperature.

Of these instruments there are two general types, the high resistance and the low resistance. The couples of the former consist of small-diameter wires of platinum and an alloy of platinum and rhodium protected against

breakage and deterioration by porcelain or iron tubes. Low resistance couples are usually made of alloys of nickel, iron and copper.

A temperature measuring instrument suitable for temperatures not in excess of 1000 deg. F. is a mechanical pyrometer consisting of two rods of some substances having different rates of expansion such as iron and brass or graphite and iron, connected by gears and levers to impart motion to a pointer moving across a graduated dial. For accuracy the entire length of the tube, enclosing the rod, should be placed within the chamber within which the temperature measurement is being made.

For high temperature work, pyrometers of the radiation and optical type and Seger cones are extensively employed. In one of the former, heat rays are focused upon a miniature thermo-couple and the temperature is indicated by the use of a sensitive galvanometer. These instruments have a satisfactory temperature range of from 800 to 4000 deg. F., with an error of about 2 or 3 deg. F. at the lower temperature and not more than 20 deg. at the upper.

Various kinds of oxides mixed to give a definite melting point and formed into pyramids approximately 2 in. high are used in Seger cones. These are numbered according to their melting points. When a cone reaches its melting point the tip falls over and touches the surface upon which it rests. The following table indicates the melting temperature of Seger cones:

Cone No.	Deg. F.	Cone No.	Deg. F.
.022	1110	20	2790
.011	1380	26	2880
.010	1740	30	3040
.020	2030	35	3220
7	2320	39	3420
15	2615	42	3600

Pyrometers and high-temperature thermometers may be best calibrated by checking their indications with the known melting points of various metals such as tin, lead, zinc, antimony, silver, gold, nickel and platinum.

Engine Indicators

TYPES, THEIR USE AND CARE

GENERALLY the indicator is used for checking valve settings, determining the power developed in the cylinder and for approximating the steam consumption of the engine; but its field of usefulness is of greater extent. On the steam pipe, it will show the pressure drop, due to small or long pipe; on the exhaust pipe, it will locate excessive back pressure, whether due to small port openings or exhaust pipe; on the boiler, it will register pulsations due to the cutting off of steam valves; it also affords a means of checking pressure gages for correctness. Additional use may be made of the diagrams which, when transferred to paper ruled logarithmetically, furnish a means of determining accurately the steam used, the clearance in the cylinder and the leakage to or from the cylinder.

Indicators may be of the inside or the outside spring type, although the latter appears preferable for the reason that the spring is not only more accessible, but due to its constant contact with the air is not subject to the high temperatures apt to be encountered within the cylinder, this especially when superheated steam is used. Scale of spring to employ is dependent upon the pressure of the steam under which the engine operates at the time of taking the cards and should be only such as will provide a card about 2 in. high.

Movement of the piston is multiplied by a parallel motion which carries a pencil point held against the paper on the drum as the latter rotates back and forth. The drum which moves in unison with the piston of the engine is rotated by means of a cord wrapped around its base and connected to the engine crosshead by means of some form of reducing motion, this drum spring holding the cord taut on the return stroke.

Much depends upon the pencil movement, the function of which is to produce at all points of the stroke parallel movement of the pencil, this motion being proportional to the piston travel. The pencil movement should be light but strong and so constructed that the parts will not be subject to wear which causes lost motion and results in incorrect diagrams.

When two or more cards are to be taken simultaneously as on compound engines under test it is usual to provide indicators equipped with electromagnets by means of which the pencil may be applied to the drum at will. The circuits supplying current to these magnets are closed by a single control switch or button, thus bringing the indicators into action simultaneously.

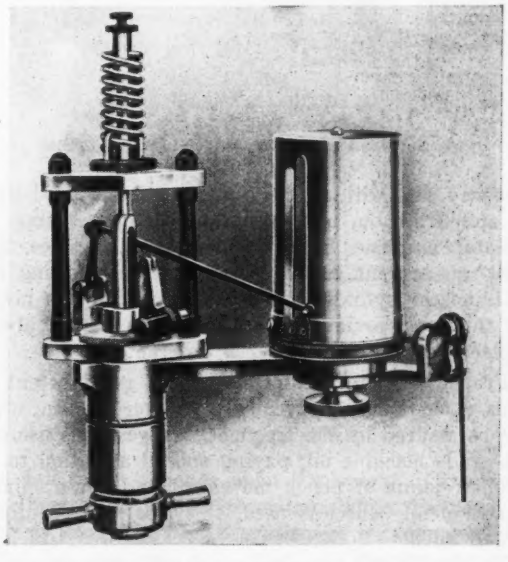


FIG. 1. INDICATOR OF EXTERNAL SPRING TYPE

Figure 3 illustrates a continuous card indicator, a type of instrument desirable on work under variable load conditions.

Installation and Care of the Indicator

As a rule, the cylinders of modern steam engines are already tapped for indicator connections when erected. Occasionally, however, the engineer must drill and tap these holes himself and when doing so should take care to have them sufficiently far into the clearance space so that they will not be partially covered at the end of the stroke and thereby render the diagram worthless. One-half-inch pipe and fittings with standard thread should be used.

After having placed nipples and elbows in position on the cylinder ends, cut a piece of pipe about 1 in. shorter than half the length between the two elbows and thread each end. Screw the pipe into one elbow; then place a three-way cock at the other end of the pipe. Next remove the large nut at the end of the three-way cock and insert a piece of pipe, marking it so it will just clear the face of the elbow; then cut it off and thread one end. Slip the large nut into the pipe and screw the pipe into the elbow, packing the joint where the pipe enters the

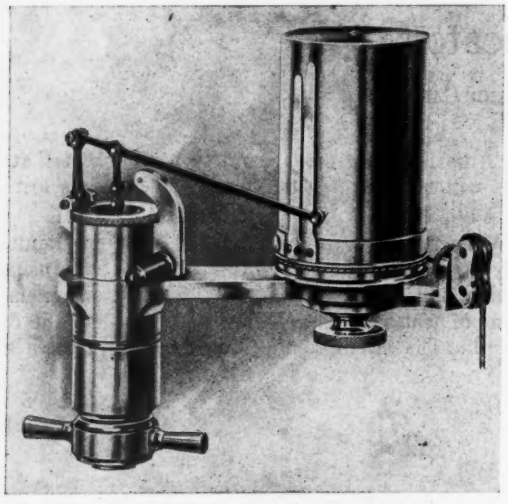


FIG. 2. INDICATOR OF INSIDE SPRING TYPE

three-way cock with candle wicking or other good packing and draw the nut up tight. Before putting the indicator in place, however, blow out the pipes thoroughly to prevent any dirt or grit from working into the indicator cylinder. When the indicator is not in use, the cap provided for the purpose should always be placed on the cocks to keep out the dirt.

Proper indicator performance to a great extent depends upon the free movement of its mechanism, which may be assured by the frequent and generous use of a high-grade machine oil, paying special attention to the cylinder, joints of pencil movement and drum spindle. If a reducing wheel is used, this also will require to be well oiled.

Tension in the drum spring should be increased for high speed and decreased for low speed, so as to allow the drum to revolve without slack in the cord on the return stroke.

Relative to the use of indicators Moyer makes the following suggestions:

Springs must be calibrated frequently.

The tension of the spring in the drum should be adjusted so that the drum revolves without slackness in the cord on the return stroke. If the cord sags on the return stroke the error may be considerable, but if the tension of the cord does not vary a great deal, errors due to stretching of cords of ordinary lengths are not serious.

Before an indicator is used all working parts should be cleaned and oiled. The piston and its rod should be examined before attaching the spring to determine by lifting the pencil lever and letting it fall whether these parts move easily. Attach the spring firmly and observe carefully that there is no lost motion. This precaution is most important in indicators having a bead on the spring for making a ball-and-socket joint. To put this kind of spring in place properly, the piston rod should be screwed tightly into the piston when the lower adjusting nut is loose. Then screw up this nut just tight enough to permit a slight movement. If the nut in the piston has been properly adjusted, there should be no lost motion between the rod and the piston, and

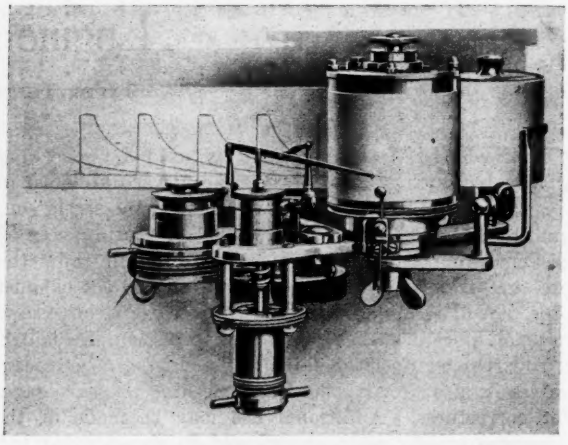


FIG. 3. TYPICAL CONTINUOUS CARD INDICATOR

still there should be flexibility in this joint permitting the piston to adjust itself in the indicator cylinder.

Oil the piston with cylinder oil every time it is taken from the cylinder. Many careful engineers oil the piston regularly after taking about 10 diagrams. A new piston usually requires more lubrication than one that is well worn.

Adjust the handle on the pencil motion so that when the pencil is sharp it will draw a very fine point. If the pencil presses heavily on the paper, friction and shifting of the paper may distort the diagrams.

Adjust the length of the indicator cord. If too short, it will be broken when the engine is started and may also injure the indicator; and if too long, the drum will strike against its stops and gives a deformed diagram. After adjusting the length of the cord the engine should be turned over by hand to make sure the cord is of proper length.

Immediately after a diagram has been taken it should be examined and any irregularities or faults noted and corrected.

Mark diagrams plainly as regards head and crank ends of double-acting engines, the time, scale of spring, and name or initials of the person taking them.

Flue Gas Analyzers and Recorders

Construction and Method of Using Manually and Automatically Operated Apparatus

BY ANALYSIS of the flue gas it is possible to determine definitely the exact conditions of combustion in the furnace. In power-plant practice the volumetric determination is the most common and simplest to perform.

In order to obtain an average sample of the gas, a sampling tube should be provided which extends well into the boiler flue. A convenient and common method is to provide an observation hole which is usually located about 24 in. on the furnace side of the damper or junction to the main flue. In this hole is inserted a wrought-iron pipe 1.75 in. in diameter, flanged at the top and set into the flue with fire clay. When not in use, this observation hole is closed by placing a 1.5-in. bolt into it.

The sampling tube may be made of Bohemian glass combustion tubing, porcelain, or a water-cooled metal tube. This tube is provided with holes along the sides

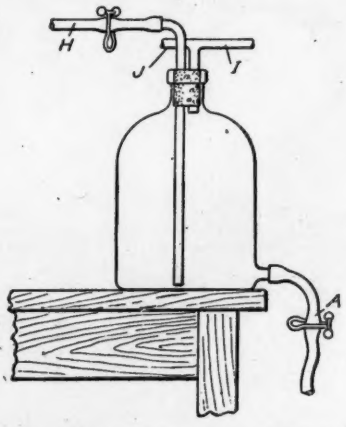


FIG. 1. SAMPLE HOLDER FOR FLUE GAS TEST

through which the gas is drawn. Care should be exercised in inserting glass or porcelain tubes as the sudden change in temperature is liable to break them.

Sample Holder

SOME FORM of gas sample holder should be provided when it is desired to take tests of the average quality of gas at intervals. This holder should be of sufficient capacity to hold 150 to 200 c.c. of gas and may be of the form shown in Fig. 1. The bottle is provided with a cork through which are passed two tubes, one of which connects through rubber tube, H, to the water supply, and extends to the bottom of the bottle, the other extends merely through the cork and is provided with a T connection, one branch of which, J, is connected by means of glass and rubber tubing to the sampling tube, while the other, I, connects to the suction side of the aspirator or pump, used to draw the gas to the testing apparatus. From the bottom of the bottle is a glass tube with a rubber connection which carries the water to waste.

To operate this apparatus, pinch cock A is closed and H opened, thus allowing the water to fill the bottle completely. Pinch cock H is then closed, and J opened, and the gas drawn through the T by the gas pump in order to remove all air which may remain in the gas connections. After this has been running for some time, I is closed and pinch cock A opened, thus allowing the water in the bottle to drain out and draw in the flue gas through tube J, when A is again closed.

In order to discharge the gas into the testing apparatus, tube I is connected to the gas instrument, the pinch cock on J closed, and by opening pinch cock H, water flows to the bottom of the bottle and forces the gas into the instrument.

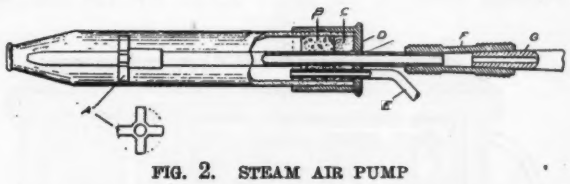


FIG. 2. STEAM AIR PUMP

For drawing the gas into the sampling apparatus, three forms of pumps are in general use. These are jet pumps, fall pumps, and steam pumps. The Richards jet pump consists of a water jet, resembling very much the common boiler injector with an air or gas connection and a restricted portion with a zigzag tube which is used for breaking up the water into foam, the principle of operation being that water entering at the top draws the air or gas through the side connection by forming successive pistons through the restricted passage.

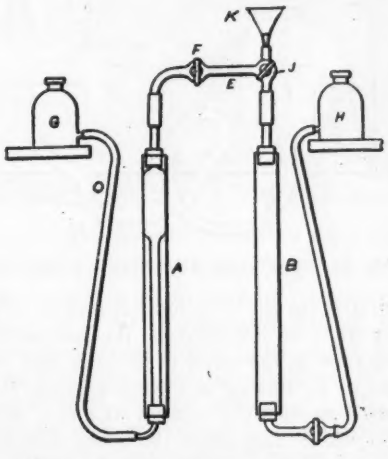


FIG. 3. ELIOT GAS APPARATUS

A fall pump depends upon the weight of the water to maintain the vacuum or suction, while the steam air pump as shown in Fig. 2 consists of a large tube contracted at one end into which is inserted cemented cork B, fitted with covering D, provided with steam tube G, and air tube E, the steam tube extending nearly to the contracted end of the large tubing and held in place by washer A. The steam connection is made through pipe G, and when turned on draws air or gas through connection E.

Analyzers

One of the simplest and most common pieces of apparatus used for analyzing flue gas is known as the Eliot, and consists of measuring tube A, treating tube B, with top connection E, provided with stop cock F, and 3-way cock J. Pressure bottles, G and H, are provided with rubber connections to tubes A and B, Fig. 3.

Before using, the apparatus should be thoroughly cleaned with water which is passed through the tubes, back and forth, by means of pressure bottles G and H. Distilled water is then put into the tubes and bottles, and the bottles placed upon shelves provided for that purpose with stop cocks F and J closed.

Connection is made to the gas holder through J, which is turned to open straight from tube B. By lowering bottle H, the gas is drawn into the treating

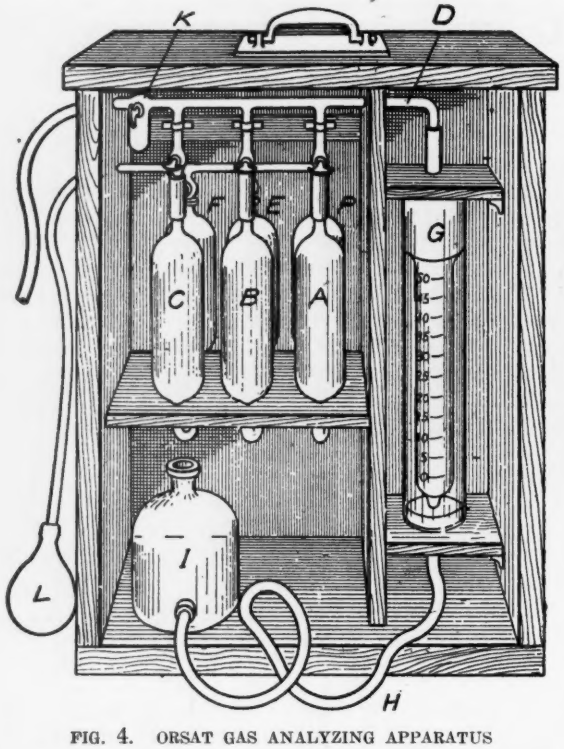


FIG. 4. ORSAT GAS ANALYZING APPARATUS

tube when J is turned to connect B and E. By opening F, raising H, and lowering G, the gas is drawn into measuring tube A, the water in G being kept at the same level as in A, by raising or lowering bottle H. Tube A is graduated so that the amount of gas it contains can readily be determined from the scale, and for convenience this amount is usually 100 c.c. Stop cock F is then closed and with J opened, bottle H is raised until all remaining gas is expelled from tube B.

By turning J, E is connected to B, F is then opened and the gas passed into B for treatment.

A 5 per cent solution of caustic potash is then poured in by means of funnel K, and allowed to drip along the sides of the treating tube until no further absorption takes place. The gas is then passed into A and measured, its loss in volume, which was carbon dioxide, being noted.

Treatment for oxygen is then proceeded with, using, instead of caustic potash, a solution of 5 grams of pyrogallic acid in 15 c.c. of distilled water, added to 120 grams of caustic potash in 80 c.c. of water, which is dropped from funnel K into B, measuring the gas and noting the loss of volume due to absorbing the oxygen.

Carbon monoxide is then absorbed by a solution made from 10.3 grams of copper oxide in 100 c.c. of concentrated hydrochloric acid.

In each case the amount of gas originally drawn being 100 c.c., the decrease in volume represents the percentage of the gas which has been absorbed by the treating solution. The chemicals must be used in the order indicated or the results will not be correct. Care must be taken when passing gas back and forth and when letting in chemicals that no gas escapes and no air enters the apparatus.

For good combustion, the gas should analyze from 8 to 10 per cent of carbon dioxide, 10 to 12 per cent of

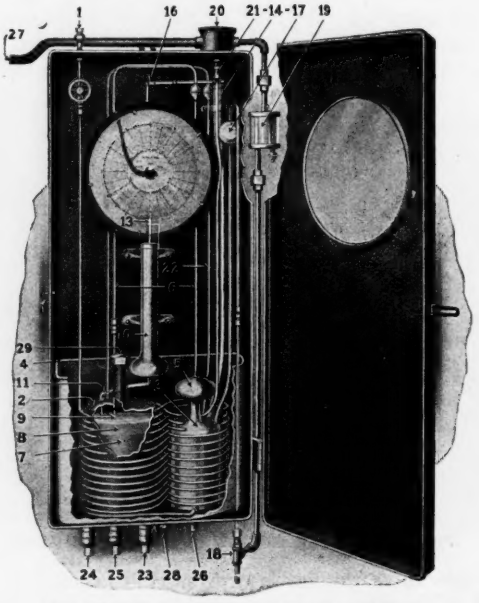


FIG. 5. AUTOMATIC RECORDING ORSAT

oxygen, and merely a trace, if any, of carbon monoxide. The balance of the flue gas is principally nitrogen and its exact determination is of little consequence after the percentages of the above three gases have been ascertained.

Orsat Apparatus

Another form of gas analysis instrument is that devised by Orsat. This consists of three pipets, A, B, C, which are connected at the top through stop cocks to a common tube, D, and at the bottom to reagent bottles, P, E and F, by flexible rubber tubing. A graduated buret or measuring tube, G, is connected at the bottom through the rubber tubing, H, to pressure bottle I. Tube D connects the measuring tube to the source of the gas supply, through cock K.

To operate this apparatus, the pressure bottle is filled with water and raised until the water level in the measuring tube reaches connection D, with stopcock K open. The gas connection is then made and, by lowering the bottle, gas is drawn into the measuring

tube until its volume reaches 100 c.c. With stop cock K closed, the gas is then passed into pipets A, B and C in the same manner as with the Eliot apparatus, and the volume of the gas noted in each case after treatment. The reagents employed are the same as with Eliot apparatus, and are passed into pipets A, B, C by pressing bulb L.

Automatic Recorders

An Orsat instrument of the automatic recording type is shown in Fig. 5. A solution of caustic potash is used as a reagent and operation is dependent upon the flow of a stream of water and the periodic operation of an automatic syphon. There are three moving members, a clock movement for rotating the chart, a pen-actuating float and a dotting mechanism.

Frequency of analysis is governed by the operating period of the automatic syphon which is regulated by a valve in the water inlet pipe. Water operating the

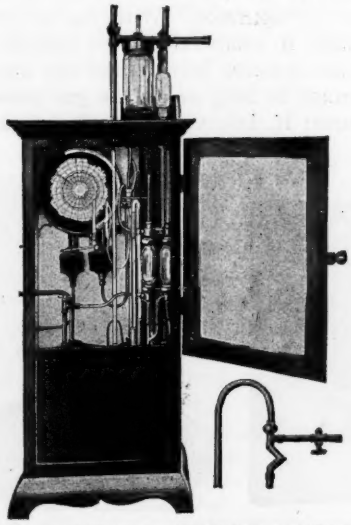


FIG. 6. CO_2 RECORDER EMPLOYING MERCURY VALVE

instrument enters through inlet pipe 1 and flows through coils surrounding absorption vessel 2 and measuring vessel 3, submerged in water tank 4; water passing through the coils equalizes its temperature and that of the water in the tank maintaining the mechanism and the gases at practically uniform temperature.

The water flows through the coils into measuring vessel 3 and traps a definite voume of gas in bulb 5, forcing it over through tube 6 to absorption vessel 2, where it bubbles up through caustic solution 7, which absorbs the CO_2 present. Above the caustic solution is a layer of oil 8, and above that gas chamber 9. A float tube, 10, terminates in tube 11, which extends through the oil almost to the level of the caustic solution. Pressure in chamber 9 causes oil to flow through tube 11 into float tube 10, which encloses a float carrying pen 13. Movement of this pen is dependent upon the quantity of gas forced into the gas chamber by the rising water—the gas reaching the gas chamber being the residue of the original sample after the CO_2 is removed. The water rising in float tube 14 raises a float which operates dotting mechanism 16, causing the pen to press against the chart.

The water now syphons out through 17, and, as the syphon takes water away faster than it is delivered, the float in 14 drops, releasing pen 13. As water continues to syphon out, pressure in the gas chamber decreases and eventually balances to atmospheric through exhaust pipe 22, the float in tube 10 dropping to normal position. Water passing through the syphon operates aspirator 18, creating suction through water seal 19, and draws flue gas through filter 20. Part of this is drawn through the filter into measuring vessel 3 through intake pipe 21. When syphon 17 breaks, pressure of the gases in measuring vessel 3 balances and the cycle is resumed by the rising water trapping the unit quantity of gas in bulb 5.

The distinguishing feature of the CO_2 recorder illustrated in Fig. 6 is a mercury valve. By means of a system of tubes and this valve, a fixed quantity of gas is trapped and passed through a vessel containing caustic

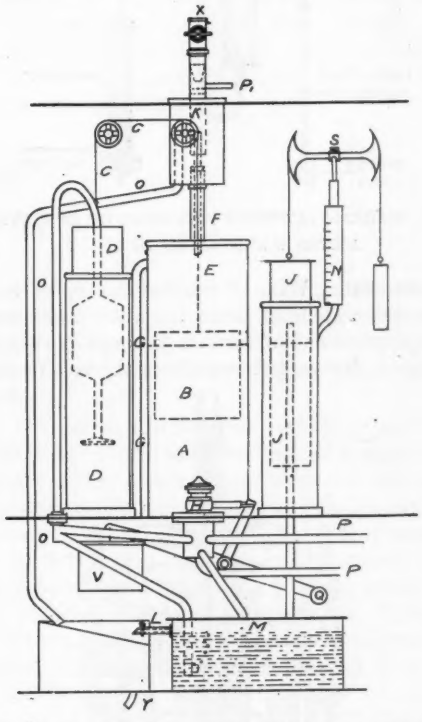


FIG. 7. CO_2 RECORDER EMPLOYING BELL FLOATS

potash by which the CO_2 is absorbed, the reduction in volume operating so as to show on the chart the percentage of CO_2. Water rises and falls in these tubes and by means of the mercury valve and a water overflow, the levels of the liquids are automatically corrected at the end of each cycle of analysis.

To remove soot and other foreign matter, the gas is passed through a filter. The gases are taken from the last pass in the case of a water-tube boiler or from the uptake of a fire-tube boiler, through a 1-in. pipe which leads direct to the condenser and filter, and from the filter the gases are carried by a ½-in. pipe to the analyzer.

Caustic potash used as the absorbent should be changed about once each month and the filtering material whenever necessary. Analyses are made at intervals of about 3 min.

Another instrument operated by a continuous stream of water is that shown in Fig. 7. The water enters

reservoir K through inlet X and overflows at O. A portion of the stream flows into tank A through pipe F and causes bell float B to rise, permitting bell D of the

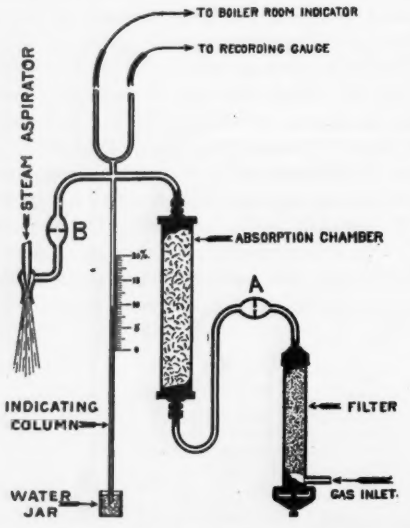


FIG. 8. DIAGRAM SHOWING PRINCIPLE OF OPERATION OF METER ILLUSTRATED IN FIG. 9

extractor to fall. When B reaches the top of its stroke, it raises valve stem E, trips the valve and causes the water to syphon out of tank A through syphon tube G. Lowering of the water level allows the bell to sink. As

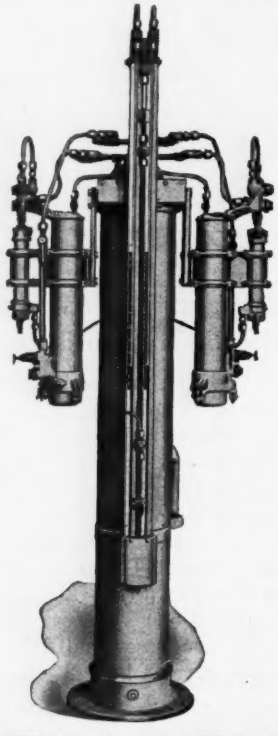


FIG. 9. METER OPERATED ON PRINCIPLE THAT CHANGE OF VOLUME PRODUCES A CHANGE OF PRESSURE

it descends it draws up water-sealed extraction bell D and creates a partial vacuum under this. Flue gas then flows from the source of supply through P and H into the bell. The water discharged from syphon tube G into small vessel V beneath it overcomes counterweight and closes balance valve H, thus entrapping a fixed volume of gas in the extractor bell.

The stream of water flowing into tank A causes float B to rise and bell D to sink, as before. Lowering of bell D forces the entrapped flue gas through the caustic potash solution in vessel M into water-sealed recorder bell J, the displacement of which is less than that of bell D by the volume of CO_2 absorbed in vessel M. The percentage of CO_2 is thus indicated by the position of bell J with reference to graduated scale N. The pen mechanism is attached to bell J and records the percentage of CO_2 by the length of lines on a clock-driven chart.

In the operation of the instrument shown in Figs. 8 and 9 a somewhat different principle of operation is employed. The gas to be analyzed is drawn through two apertures, A and B, Fig. 8, by a constant suction produced by an aspirator. With the apertures maintained constant in temperature, the suction or partial vacuum in the chamber between the two apertures will remain constant as long as all the gas passes through both apertures; if, however, part of the gas be taken

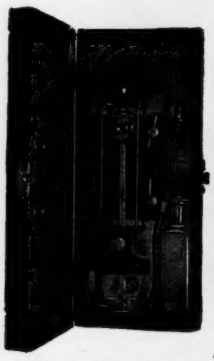


FIG. 10. CO_2 INDICATOR OF THE PORTABLE TYPE

FIG. 11. SIMPLE GAS ANALYZER WHICH READS CO_2 DIRECT

away or absorbed, as by the absorption chamber shown in the space between the two apertures, the vacuum will increase in proportion to the amount of gas absorbed. If a light vacuum gage is connected with this chamber by means of the connections indicated, the amount of gas absorbed will be indicated by the gage reading so that the gage can be readily calibrated in per cent CO_2 in the flue gas. Each instrument is provided with an indicator and a recorder and, owing to the flexibility in the matter of installation, the meter can be located in any clean and convenient part of the plant, while the indicator can be placed in the boiler room for the guidance of the fireman and the recording gage mounted in yet another location.

Two small portable so-called pocket CO_2 indicators are illustrated in Figs. 10 and 11. With the former, the time required to make one determination is about 2½ min. To operate, the lower bulb is filled with a solution of caustic potash; a sample of the flue gas is then pumped through the upper cock into the graduated neck of the instrument. When this has become

completely filled with the gas to be tested the upper cock is closed and the lower cock turned 180 deg. which permits the gas and caustic potash to come into intimate contact. The caustic potash absorbs the contained CO_2, forming a partial vacuum in the instrument. After sufficient time for this chemical action to take place, the lower cock is closed and the instrument inverted and immersed in water. The upper cock (the one through which the gas entered the instrument) is opened and water enters to take the place of the CO_2 absorbed. After closing the cock again and bringing the apparatus to normal upright position the per cent of CO_2 is read off on the tube at the water level.

The instrument shown in Fig. 11 consists of a cored cylinder with hollow extended base. To this cylinder is connected a delicate vacuum gage, the hand of which swings over a scale calibrated to read the percentage of CO_2 in the gas.

Caustic potash solution with a small percentage of mineral oil is poured into a funnel near the bottom of the cylinder, the vent at the top being open to allow the escape of air. About 12 oz. of this solution is used for one charge which is sufficient for 300 tests. The oil at once separates, rising to the top of the liquid, thus sealing the surface of the caustic potash from the gas in the cylinder and keeping it unaffected until the instrument is shaken.

By means of a special connection, a hose is connected to the sampling tube and with both cocks open gas is pumped in at the top and out at the bottom of the cylinder, thus giving it a thorough scavenging; closing the upper, then the lower cock traps the sample to be tested. The instrument is then shaken, which exposes the caustic potash to the gas and the CO_2 is immediately absorbed, creating a vacuum in the chamber proportional to the amount of CO_2 in the sample; this vacuum in terms of per cent CO_2 is indicated upon the dial.

The oil then rises rapidly to the surface of the liquid, sealing it from the contents of the cylinder and the instrument is ready for another test.

Calorimeters

How Constructed and Used

WHEN the moisture present in steam does not exceed 5 per cent, the most suitable calorimeter for use under pressures ordinarily employed is the throttling such as shown in Fig. 1. Essentially this consists of an insulated chamber, C, fitted with an orifice, O, having a diameter of about 1/16 in., a thermometer well, W, and provided with steam, exhaust and manometer connections in the manner indicated, the steam connection being made by means of a valve, V_1 and a sampling pipe. This, according to A. S. M. E. recom-

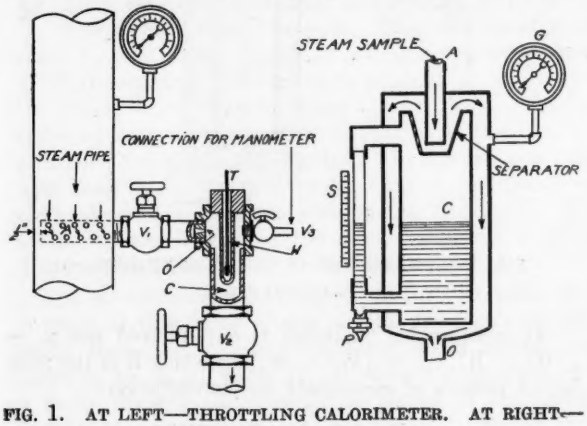


FIG. 1. AT LEFT—THROTTLING CALORIMETER. AT RIGHT—SEPARATING CALORIMETER

mendations, should be ½ in. in diameter with at least 20, ⅛-in. holes uniformly drilled in spiral rows; the pipe should be closed at its end and should extend to within ½ in. of the farther wall of the steam pipe.

Steam from the sampling tube passes through the orifice and into chamber C where its pressure due to its passage through the orifice and its ready means of discharge through valve V_2 is but slightly in excess of that of the atmosphere.

As, with superheat not existing, the heat contained by 1 lb. of steam at high pressure is greater than that contained in steam at low pressure, the steam upon reaching chamber C contains an excess of heat which evaporates the moisture carried in with the steam and superheats both.

With the assistance of a table showing the properties of saturated steam and readings of a gage showing the pressure of the steam in the pipe, the thermometer and the manometer, the quality or relative dryness of the steam may be readily determined either mathematically or by means of a chart designed for that purpose. With P_1 representing the pressure of the steam in the main, in pounds per square inch absolute, P_2 the pressure of the steam in the calorimeter also in pounds per square inch absolute (manometer reading plus atmospheric pressure), r_1 and h_1 the heat of vaporization and heat of liquid respectively, corresponding to pressure P_1 expressed in B.t.u., H_2 and t_2 the total heat (B.t.u.) and temperature (degrees Fahrenheit) corresponding to pressure P_2, C the specific heat of superheated steam which for all practical purposes may be taken as 0.47, t_s the actual temperature in chamber C as measured by the thermometer, x_1 the initial quality of steam and $1\text{-}x_1$ the initial moisture in steam, the value of x_1 is determined by the formula:

$$x_1 = [H_2 + 0.47\ (t_s\text{-}t_2) - h_1] \div r_1$$

Accurate results are obtainable by the use of the chart shown in Fig. 2. Let us assume the pressure within the pipe to be 175 lb. absolute, the temperature within the calorimeter 290 deg. F. and the reading of the manometer such as to indicate a pressure of 15.5 lb. within the calorimeter. From the intersection of the 290 deg. F. temperature ine and the 15.5 lb. pressure line we find by following the horizontal dotted line to the left to the 175 lb. pressure line that the dryness quality of the steam is 0.988 or 98.8 per cent, or that the per cent of moisture present is equal to 1.2 per cent.

Separating Calorimeters

Shown in Fig. 1, at right, is a typical separating calorimeter, an instrument particularly well adapted for the determination of moisture in steam carrying more than 5 per cent entrained water. Mechanical separation is employed in this instrument. Steam at A, passes down through the vertical pipe into the perforated basin or separator from which the dry steam escapes, passing down through the jacket and out of orifice O into the atmosphere.

The weight of steam passing through this orifice each second is equal to the quotient obtained by dividing the product of the absolute pressure in pounds per square inch behind the orifice and the area of the orifice in square inches, by 70, and as in each instrument the value of the area of the orifice is fixed, it is evident that the gage may be calibrated in pounds flow per second instead of in pounds pressure, thus giving a direct reading and eliminating much calculation.

In operation, a sample of steam is caused to pass through the calorimeter and, after the instrument is

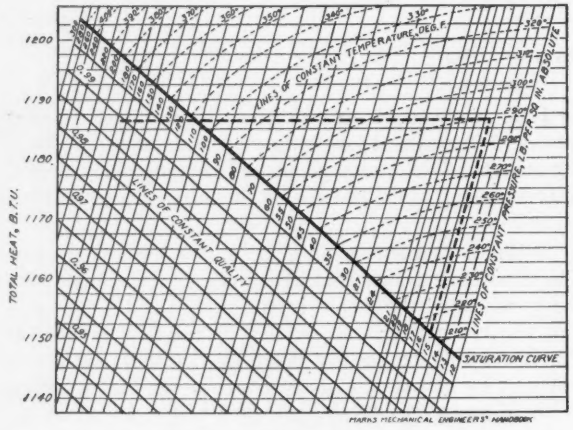


FIG. 2. CHART FOR DETERMINING QUALITY OF STEAM

well heated, initial and final readings of scale S are made together with a number of gage readings to determine an average value. Multiplying this average reading by the number of minutes operation indicates the total number of pounds of steam flowing which when divided by the sum of this total number of pounds of steam and the number of pounds of water taken into the separator (that is difference between initial and final scale readings) will give the quality.

Combined Calorimeters

The apparatus shown in Fig. 3, a combined separating and throttling calorimeter, is more suitable for the determination of moisture in low-pressure steam than either of the other types. By use of the separating calorimeter most of the moisture is removed and the small remainder is registered by the throttling calorimeter. This discharges into a receiver in which a high vacuum is maintained.

The ⅜-in. brass nozzle of the sampling tube of this calorimeter described in the 1910 Trans. A. S. M. E. is filed to a knife edge to reduce the disturbance of the steam current to a minimum and should be located at a distance of 1/6 the diameter of the pipe from its side. The lever cock between the two calorimeters produces the necessary throttling action. In the throttling member, steam is condensed in a vacuum receiver from which it flows to a volumetric measuring tank.

The spy glass is for the purpose of observing the passage of moisture.

When using the combined separating and throttling calorimeter, the quality of the steam may be determined by employing the following formula:

$$x_1 = (W_2 x_2) \div (W_1 + W_2)$$

where W_1 is the weight of moisture in pounds collected in the separating calorimeter in a given interval of time, W_2 is the weight of dry steam condensed after passing through the throttling calorimeter and x_2 is the quality of steam discharged from separating portion and as determined by the throttling calorimeter.

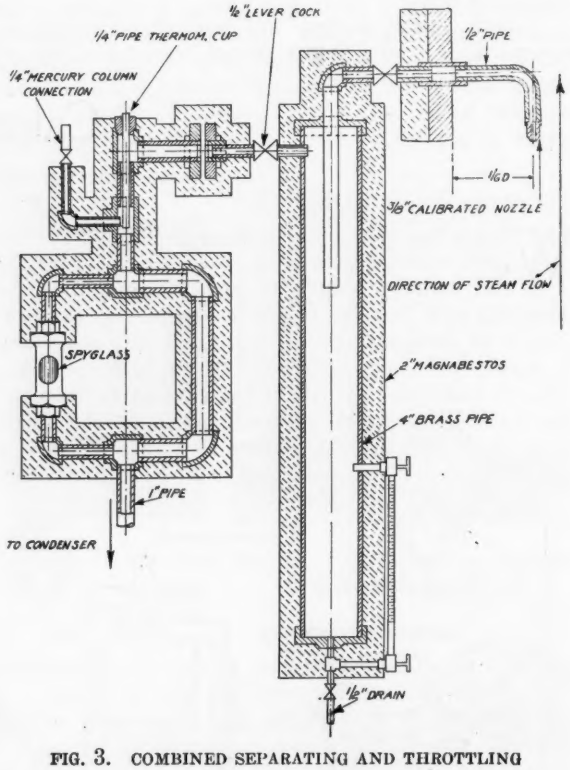


FIG. 3. COMBINED SEPARATING AND THROTTLING CALORIMETER

If considerable radiation is encountered use $x_1 = [(W_2 + R) x_2] \div (W_1 + W_2)$ in which R is the number of pounds of condensate due to radiation.

Barrel Calorimeters

Where other types are not available and no great degree of accuracy is required, the barrel calorimeter will be found serviceable. This consists of a barrel of water mounted on a platform scale and connected to a source of steam supply by means of a sampling tube, the open end of which extends below the surface of the water in the barrel, a thermometer for reading the temperature of the condensing water and a pressure gage attached to the steam line.

After the barrel is filled with water to within about

6 in. of the top, the temperature is observed and the weight carefully noted. With the sampling pipe drained of all moisture and condensate, the steam is turned on for a period sufficiently long to bring the temperature of the water as much above that of the room as it was below. The steam is then shut off and the weight and temperature again observed and noted to determine the amount of steam added and the temperature rise.

While making this test, it is well to stir the condensing water vigorously and to eliminate the necessity of making a correction for the heat absorbed by the calorimeter, it is advisable, previous to making the test, to fill the barrel with water heated to a temperature of about 150 deg. F. by the addition of hot water, and then carefully drain. Spite of this precaution, however, it is in the interest of accuracy to calculate the water equivalent of the heat absorbed by the barrel which may be done in the following manner: Multiply the weight of water added in pounds by the difference between the temperature of the water added and the temperature of the mixture (both in degrees F.) and divide the product by the difference between the temperature of the mixture and the temperature of the original water in the calorimeter. From the quotient then obtained subtract the weight of the water first placed in the calorimeter.

Without losses or where correction has been made for such, it is obvious that the heat lost by the steam is equal to that gained by the water. Or expressing this mathematically, we have $(x_0 r_0 + q_0 - q_2)\ W_2 = (W_1 + c)\ (t_2 - t_1)$.

Where W_1 is the weight of water in calorimeter in pounds; W_2 the weight of steam added in pounds; c is the water equivalent as determined above; t_1 initial temperature of water in calorimeter in degrees F.; t_2 final temperature of water in degrees F.; P_0, pounds pressure of steam; r_0, heat of vaporization of steam (B.t.u.) corresponding to P_0 and q_0 and q_2 the sensible heat of liquid (B.t.u.) corresponding to P_0 and t_2.

The value of x_0 or quality of the steam may then be determined by transposing the above formula thus giving:

$$x_0 = \frac{(W_1 + c)\ (t_2 - t_1)}{W_2\, r_0} + \frac{q_2 - q_0}{r_0}$$

Calibration

Separating calorimeters may be calibrated in the following manner. Allow chamber C of the instrument shown at the right of Fig. 1 to fill with water separated from steam passing as in operation, noting the reading of scale S after shutting off the steam. Then through pet cock P allow an amount of this water to drain into a flask containing cold water and after closing this pet cock, again note reading of scale S. The difference between the two scale readings should be equal to the gain in weight of the receiving flask with contents before and after taking water out of the calorimeter.

Testing Heat Values of Fuels

Calorimeters, Their Construction and Use

FOR determining the heat value of coal the Mahler bomb calorimeter, Fig. 1, is the most accurate device so far brought forward. This consists of steel shell, B, with cover, capable of withstanding a pressure of 50 atmospheres. The capacity is about 40 cu. in. and the weight 9 lb. The walls are 0.3 in. thick. The interior is lined with a coating of enamel to resist corrosion and the outside nickel plated. In the cap is a tube with stop cock, through which runs a well-insulated electrode with a platinum wire on the inner end. The second platinum wire of the circuit supports a small disk on which the fuel to be burned is placed.

The calorimeter vessel holds about 5 lb. of water and is made of thin brass of size to hold the bomb conveniently immersed. A screw agitator works outside the bomb to bring all water to the same temperature and a finely divided thermometer is placed in the water. Outside the calorimeter shell is a layer of non-conducting material and occasionally the whole apparatus is enclosed by another vessel containing water to prevent radiation.

Care should be taken that the ignition wire dips well into the coal and that the fuel, if anthracite, be powdered very fine, at least to pass through a screen of 100 mesh to the square inch; bituminous coal may be somewhat coarser. Caution should also be taken to see that there is no leakage around the bomb. This can be detected by watching the gage after the bomb is filled with oxygen and the tank has been shut off. If there is a leak the pressure gage reading will drop gradually.

To use the apparatus, a gram, or 15.4 grains avoirdupois, of fuel is weighed and placed in a little porcelain dish which rests on the platinum disk at C. A fine iron wire is fastened to the electrode, F, and to the support of the disk. The cover is then put in place and firmly

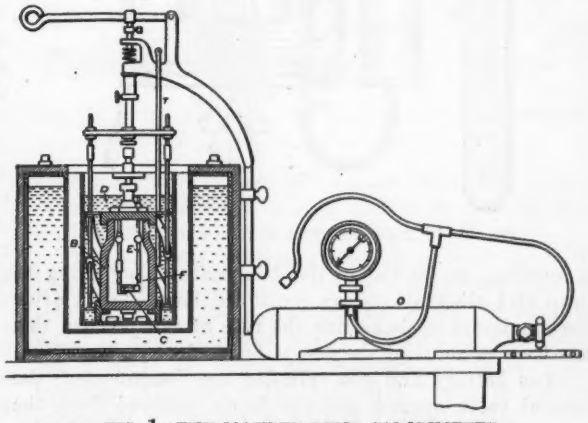


FIG. 1. THE MAHLER BOMB CALORIMETER

clamped down, joint with the bomb proper being made by a lead gasket.

The stop cock is now connected with a cylinder of oxygen which is under 50 atmospheres pressure and the stop cock opened until the required pressure inside the bomb is obtained. The connection between cylinder and bomb is then broken and the bomb put into the

calorimeter, the screw agitator and thermometer adjusted and the calorimeter filled with water which has previously been weighed.

In handling the bomb after the dish has been filled with the fuel charge, care should be taken not to tip it sidewise nor to jar it, so that none of the fuel will be spilled out of the dish.

Stir the water and take observations with the thermometer to make sure of the initial temperature.

When this has been established, connections are made from the gas cylinder to the bomb and the battery to the electrode. Current is passed through the electric circuit igniting the fuel. Thermometer readings are taken each half minute until the maximum temperature

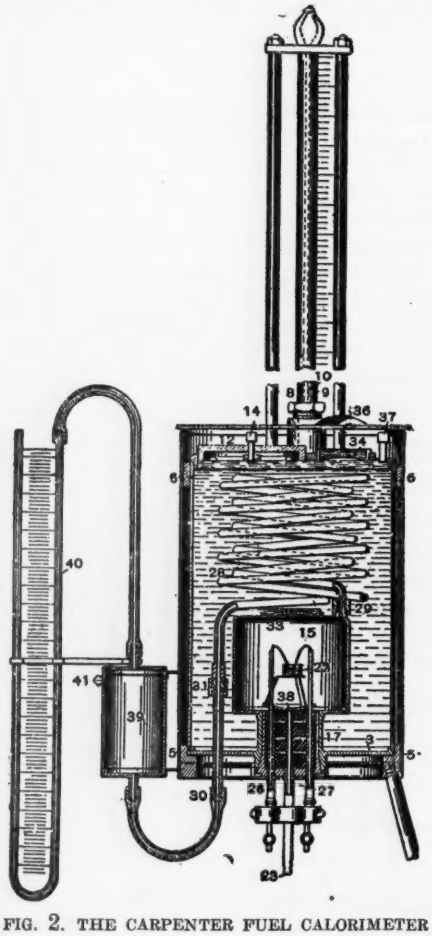


FIG. 2. THE CARPENTER FUEL CALORIMETER

is reached, as shown by the temperature beginning to drop and observations are continued long enough after the maximum to determine the rate of fall. When this has been established the test is finished.

The battery and gas cylinder are disconnected, the conical valve opened and the bomb removed from the calorimeter. The bomb is then washed out with distilled water to determine the weight of nitric acid.

Correction for cooling is a factor expressing the rate of cooling per minute. This is determined by finding the drop in temperature from the maximum over a period of 5 or 10 min. and dividing the average fall in temperature during this time by the number of minutes. This will give the fall per minute. Multiply this by the number of minutes of the combustion period and it will give the loss in temperature due to cooling.

We have then this rule: Add the difference between observed original and maximum temperatures to the correction for cooling. Then add to the weight of the water the water equivalent of the bomb and other metal parts, which will be given with the instrument. Multiply these two sums together, and from the product subtract the sum of the weight of nitric acid times 0.23 and the weight of the iron wire times 1.6. The remainder will be the heat value in calories for 1 gram of the fuel. Multiplying this value by 1800 gives the B.t.u. per pound.

THE CARPENTER CALORIMETER

THIS CALORIMETER is shown in sectional view in Fig. 2. A combustion cylinder, 15, is provided with a removable bottom, 17, through which the tube, 23, passes to supply oxygen. Also through this removable bottom the wires, 26 and 27, pass which carry electrical current to ignite the fuel. Above this removable bottom is carried the asbestos combustion dish, 22, which holds the fuel. For reflecting the heat upward from the bottom of the combustion cylinder a silvered mirror, 38, is provided so that heat does not pass downward to any extent from the bottom of the combustion cylinder. Alternate layers of asbestos and vulcanite are fastened together to form a plug of this removable bottom and the whole thing is kept in place by a tight fit into the orifice.

Products of combustion pass upward through the spiral tube, 28, and then downward through 29, 31 and 30, to the small chamber, 39, which is connected on the outer end with an open U tube gage. The water in the chamber surrounding the combustion cylinder forms a bath which is connected with an open glass gage, 10, above the water chamber. A diaphragm, 12, above the water is used to adjust the level. From the small chamber, 39, a pinhole exit, 41, serves to allow the products of combustion to escape slowly. The outer casing is nickel plated and polished on the inside to prevent radiation of heat.

Five pounds of water are placed in the bath and the charge of fuel used is 2 grams. Coal which is to be tested is ground to a powder in a mill or mortar and the asbestos cup is heated through to drive off all organic matter. This cup is then weighed, the sample placed in it and the whole weighed together. The difference gives the weight of the coal used for the test. The cup is then placed in proper position on the bottom plug which is inserted in the combustion cylinder.

Raise the ignition wire above the coal, turn on the current which will, of course, heat the air in the cylinder and cause the water to rise slightly in the glass tube. As soon as this commences, turn on the oxygen and pull down the ignition wire to kindle the coal, at the same instant taking the reading on the glass scale. Windows are provided in the top of the water chamber and the combustion cylinder so that the process of combustion can be watched and as soon as this is finished the scale reading and the time should be taken. The difference between the first and last readings will be the actual scale reading. This must be corrected for radiation.

To make this correction let the apparatus stand with

the oxygen shut off as long as it took for the combustion to take place, then take the scale reading and the time. It is assumed that the drop in the scale reading during this time will indicate the amount of the radiation which took place during the combustion and should, therefore, be added to the actual scale reading to give the corrected reading. With each calorimeter is furnished a calibration curve from which by comparison with the corrected scale reading the B.t.u. developed during the combustion can be found. The amount of ash is determined by weighing the asbestos cup after combustion. Dividing the number of B.t.u. developed during the test by the weight of coal burned in pounds gives the B.t.u. per pound.

Tests of liquid fuels are made in the same way as those for solid fuels and the same calorimeters can be used for one class as for the other.

The heating value of solid fuels, in B.t.u., may also be determined by means of the following formula:

$$\text{Heat value} = 14{,}600\ C + 62{,}000\ (H - \frac{O}{8}) + 4000S$$

where C, H, O and S are the weights in lb. of carbon, hydrogen, oxygen and sulphur respectively in one pound of the fuel.

Testing Gas Fuels

The most satisfactory apparatus for measuring the calorific power of gas is the Junker calorimeter, Fig. 3, as described in Gas and Fuel Analysis, by Gill. It is portable, burns fuel at atmospheric pressure and can be operated continuously for any length of time. This apparatus has a combustion chamber, 28, surrounded by water jacket 15, 16, through which pass a great number of tubes; air space, 36, outside serves as a jacket to prevent radiation from the water bath.

Water for the jackets is passed in at 1, goes downward through 3, 6 and 7, and leaves the jacket at 21. The gases from combustion enter the tubes at 30 and pass downward, leaving at the bottom through the space, 31, and passing outward through the outlet, 32, 33; water and gases, therefore, move in opposite directions, so that the hottest water comes in contact with the entering gases. The heat is practically all transferred from the gases to the water by the time that the gases reach space, 31.

Gas to be burned is metered and then passed into the apparatus through cock, 32. A pressure regulator is introduced between the meter and calorimeter to insure constant pressure, which makes the source of heat constant in quantity and the water in the calorimeter is provided with two overflows so as to make the absorbing quantity constant. The thermometer at 12 measures the temperature of the entering water and one at 43 that of the water leaving.

In order to determine the heating value of gas, four quantities are to be ascertained: (1) The number of cubic feet of gas burned; (2) the quantity of cooling water used; (3) the rise in temperature of the cooling water; (4) the quantity of water condensed from the exhaust gases.

In operating the calorimeter, the cooling water is first allowed to flow through the upper overflow, then the water is allowed to pass through the calorimeter by opening the regulator, e, Fig. 3, near the bottom of the calorimeter. Gas is then turned on at the meter and lighted at the burner. The flow of gas should be such that 1 cu. ft. is burned in from 10 to 15 min. Next, the cooling water should be regulated so that the increase in its temperature is only from 12 to 51 deg. The thermometers used in the cooling water are graduated to 0.1 deg.

When the required regulations are made and the temperature of the leaving cooling water is nearly constant, a run of 5 min. may be made and readings taken. Care must be taken to read the meter and the cooling water simultaneously. The temperatures of the entering and leaving water may be taken alternately each half minute so as to get their average values.

The heating value, H, of the gas may then be computed as follows:*

Subtract the average temperature of entering water from that of the leaving water; multiply by the pounds of water used and divide by the cubic feet of gas used, reducing to standard conditions of temperature and pressure, 62 deg. F. and 30 in. mercury pressure.

Water formed by the combustion of hydrocarbons collects from the exhaust gases at 34 and is drained off through outlet 35.

Under practical conditions, the water formed by the complete combustion of hydrocarbons in the gas is not

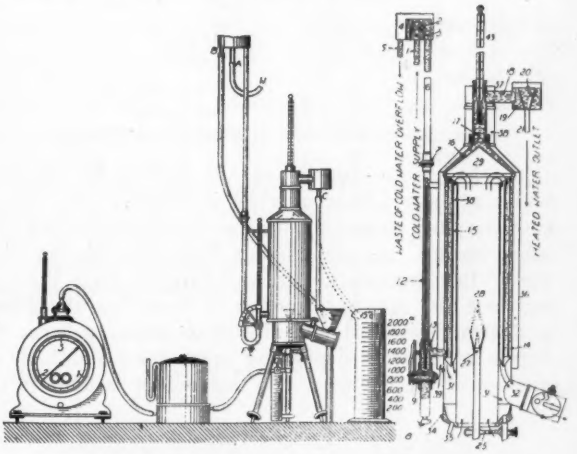


FIG. 3. THE JUNKER GAS CALORIMETER; ARRANGEMENT AND SECTIONAL VIEW

condensed and does not give up its latent heat of vaporization, but passes off taking with it its heat of vaporization.

The value of H, then, is too large and the "effective" value of the gas must be determined. To find the "effective" value, multiply the weight of condensed water in pounds by 966, divide the product by the number of cubic feet of gas and subtract the result from H, this new value, H^1, is the "effective" value of the heating power of the gas in British thermal units.

*As a formula

$$H = (t_1 - t_2)\ W \div V$$

in which t_1 and t_2 are the average initial and final temperatures of the cooling water, W is the weight in pounds of the cooling water, and V is the number of cubic feet of gas reduced to standard conditions of temperature and pressure, as, for example, 32 deg. F and 1.7 lb. per square inch, assuming that the volume of the gas is proportional directly to the temperature and inversely to the pressure.

$$H^1 = H - (966 \times W \div V)$$

where W is condensed water of combustion.

Electrical Instruments

Meters for Measurement of Current Flow, Voltage, Power, Frequency and Synchronism.

FOR accurate alternating-current measurements the electrodynamometer type of ammeter is extensively employed. In this the current flows through two coils, one stationary and the other pivoted, and as the pointer is attached to the latter, this is caused to swing across a graduated scale due to the force acting between the coils as a result of current flow. Although this instrument can be used also for direct-current work, the results obtained are not very satisfactory because of the small deflecting forces and the fact that the direction of deflection cannot be reversed by a reversal of current flow.

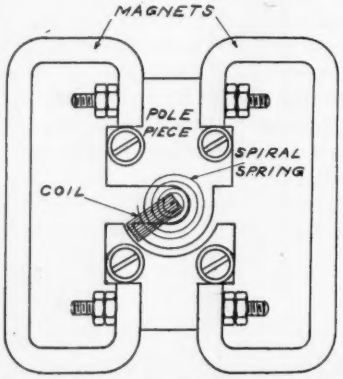


FIG. 1. TYPICAL DIRECT-CURRENT AMMETER

In the hot-wire type current is made to flow through a wire, at the mid-point of which is attached a fine thread with one turn around a small spool and terminating in a spiral spring. As the current flows through the "hot wire," this becomes heated and expands with the consequence that, due to the action of the spring, the thread is drawn downward and the spool made to turn, the degree of rotation depending upon the amount of expansion of the hot wire. As the pointer is fixed to the

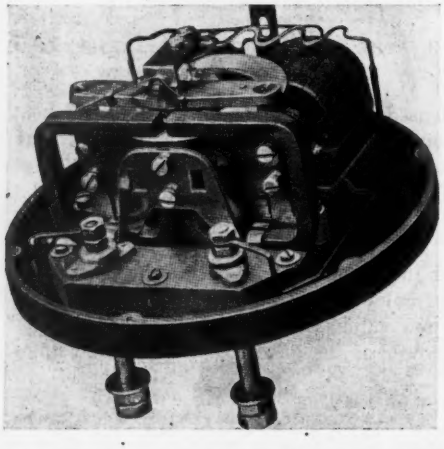


FIG. 2. TYPICAL ALTERNATING-CURRENT AMMETER

spool, its deflection is proportional to the current flow.

A common type of ammeter is the plunger instrument in which a piece of soft iron is magnetized and deflected by a coil of wire through which the current to be indicated flows; the pull of the coil is opposed by a spring. In a modified form of this type, a soft iron vane is attached to a pointer controlled by hair springs. With the design employed the vane is strongly magnetized although the current flow is but a small fraction of the capacity of the instrument.

For low rates of current flow, ammeters may be directly connected into the circuit as shown in Fig. 3, while where heavy currents are to be handled, direct-current instruments are usually equipped with shunts which allow but a small fraction of the current to pass through the instrument windings. This is illustrated in Fig. 4. For alternating current work, a current transformer is used instead of the shunt.

Voltmeters

These, except the electrostatic voltmeter, are essentially high-resistance ammeters. In the electrostatic instrument, which is generally employed for high volt-

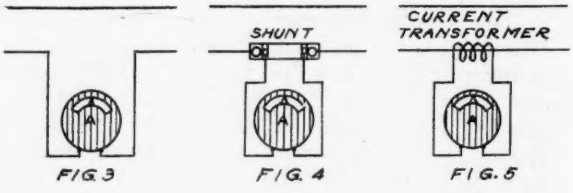


FIG. 3. AMMETER CONNECTED DIRECTLY TO CIRCUIT
FIG. 4. AMMETER CONNECTION EMPLOYING SHUNT
FIG. 5. ALTERNATING CURRENT AMMETER USED IN CONNECTION WITH CURRENT TRANSFORMER

age work only, there are two plates, one fixed and the other suspended, the latter carrying the pointer which plays over a graduated scale. Due to electrostatic attraction, when the instrument is connected to the line, these plates attract one another and as a result the suspended member is made to turn, the degree depending upon the value of the applied electromotive force.

For all direct-current work, except where so-called multiplying coils become necessary, and for low-voltage alternating-current work, voltmeters are connected as shown at A, Fig. 6; while, when used on high-tension alternating-current circuits, it is usual to employ a potential transformer and, although the voltage applied to the terminals of the instrument is much less than that carried on the line, the meter is graduated so as to read line voltage.

Watt and Watthour Meters

In Fig. 7 is shown a scheme of connection of an indicating wattmeter. Within stationary coil B is a suspended fine wire coil, A, movable and carrying a pointer which moves across a graduated scale, the degree of deflection depending upon the degree of force acting between the two coils. This, in turn, is proportional to the power in watts. R is a non-inductive resistance.

Watthour meters may be divided into three general types: Commutator meters, mercury meters and induction meters. The first consists of a small armature mounted upon a steel shaft, and revolving between two field coils, which carry the load current and produce the magnetic field in which the armature rotates. The armature or rotating element is similar to that of a direct-current motor.

Figure 8 shows the diagram of connection of such a meter in which the field coils are connected in series with the load, while the armature circuit consisting of the armature, an adjustable light-load coil, LLC, and a resistance, R, is connected across the circuit. The current through the armature winding, or pressure circuit, varies with the voltage which, on constant-potential circuits, is maintained at practically a fixed value. The strength of the field varies with the load current, and, as the torque due to the potential circuit and that due to the load current are acting at all times the meter is in operation, the torque acting on the armature is proportional to their product, or the power.

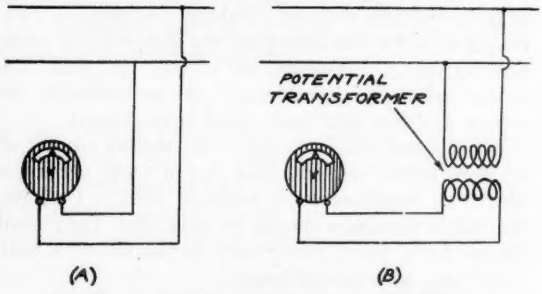


FIG. 6. A—DIRECT-CONNECTED VOLTMETER
B—VOLTMETER USED WITH POTENTIAL TRANSFORMER

In order to make the speed proportional to the power, some form of mechanical load must be provided, with a counter torque proportional to the speed. This counter torque is generally obtained by mounting on the armature shaft a disk or cup-shaped piece of copper or aluminum, arranged to revolve between the poles of several permanent magnets, producing a counter torque proportional to the speed. As the speed increases, the counter torque of the disk or generator element also increases, until a speed is reached where the two torques balance each other and the speed remains constant for a given load. Thus, neglecting friction of the moving parts, the speed of the rotating element varies with the power.

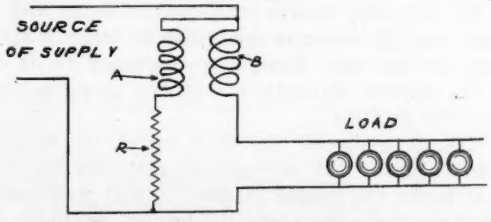


FIG. 7. DIAGRAM OF CONNECTIONS OF INDICATING WATTMETER

In addition to the main field coils, most meters of this type are provided with a smaller coil of fine wire, referred to above as the light-load coil, connected in series with the armature or pressure circuit, and mounted in such a position that its plane is parallel to that of the main or series coils. The direction of current flow around this coil is the same as that in the series coils, so that the effect of these two coils is in a like direction. This coil is commonly known as the light-load, friction or compensating coil, its function being to produce the torque required to overcome the friction of the moving parts.

The magnetic effect of this coil on the armature is usually adjustable in one of two ways: Its position with respect to the armature may be changed, resulting in increased or decreased torque, as the coil is moved to or from the armature; or, the number of active turns in the coil may be changed, resulting in a change of torque without changing the position of the coil.

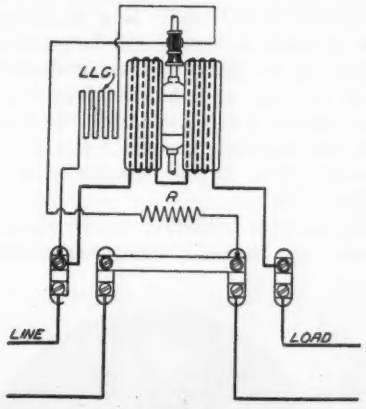


FIG. 8. CONNECTIONS OF COMMUTATOR TYPE WATTHOUR METER

Watthour meters of induction type operate on the principle of the rotating magnetic field of the induction motor. A thin disk or cup of copper or aluminum, generally used as motor and generator element, is mounted on a delicately pivoted spindle and driven by an electromagnetic device at a speed proportional to the power delivered to the receiving circuit. The essential features of this magnetic device which, of course, are more or less modified in the various makes of meters on the market, are shown in Fig. 9. Disk DD rotates in front of three magnet poles of a laminated iron structure, the lugs of which are wound with coarse-wire coils S carrying the total current delivered to the receiving circuit and fine-wire coil P connected directly across the line. C is a compensating coil. The alternating magnetic fluxes from the poles establish currents in the disk as indicated by the arrows. Potential winding P with its many turns of fine wire is highly inductive, while the

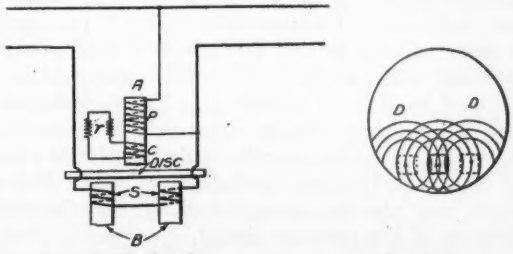


FIG. 9. ESSENTIAL FEATURES OF ALTERNATING-CURRENT INDUCTION TYPE WATTHOUR METERS

series windings S are of heavy wire of comparatively few turns, and as a result are practically noninductive. As a consequence, the fluxes produced by the potential and current circuits are approximately 90 deg. apart. Each flux is in phase with the current producing it, and the electromotive force generated in the disk which is cut by the flux is in time quadrature with the generating flux. If it is assumed, therefore, that the fluxes produced by coils P and S are in quadrature, the eddy currents produced by P will be maximum at the same instant that the flux from S is a maximum, and vice versa. As a result, a torque will be produced which is proportional to the instantaneous product of the eddy currents in the disk and the flux from the pole under which the current is flowing. With the time phase difference of the currents in coils P and E exactly at 90 deg. at unity power factor, this torque is proportional to the power used.

In order to have induction meters register correctly, it is necessary to have this time phase difference of the

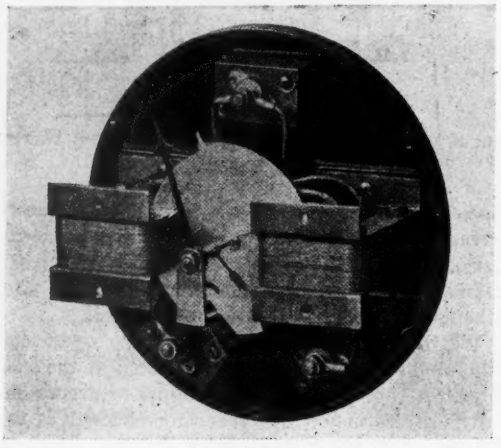


FIG. 10. INTERIOR OF FREQUENCY METER

currents in coils P and S exactly 90 deg. Due, however, to the ohmic resistance of winding P, this condition is never realized so that all induction type meters are provided with a short circuited compensating coil mounted on pole A, as shown in Fig. 9, and provided with a variable resistance r, so that by changing the value of r, the meter may be made to indicate correctly on both inductive and noninductive loads. This same result may also be accomplished by changing the reluctance of the pressure circuit.

As induction meters are not entirely free from friction, some compensation must be provided to overcome this, so that the motor may read correctly on light loads. This is generally accomplished by producing a flux at the potential pole face, slightly out of phase with the main flux. Thus eddy currents will be produced in the disk which will be in phase with a small component of the main flux, giving rise to a slight torque, which can be made sufficient to overcome the friction. A common method to produce this out-of-phase flux is to place a short-circuited copper circuit or thin copper punching in the potential pole air gap, in an unsymmetrical position, so that the desired unbalanced flux may be obtained.

Like direct-current commutator meters, the speed of induction type meters may be varied by changing the position of the damping magnets relative to the disk or cup. When disks are employed, the speed for a given load may be increased by changing the position of the magnets so that the effective flux will act nearer the shaft. Swinging the magnets out and thereby causing the flux to cut the disk at a greater distance from the shaft will result in a greater drag on the disk, with a consequent reduction of speed. The speed of meters provided with cups may be varied by raising or lowering the damping magnets. When lowered, the path of the magnetic flux of these magnets is shunted to some extent by the air gap between poles and less flux is allowed to act upon the cup, thereby increasing the speed of the revolving element. Raising the magnet, however, results in more flux acting on the cup with an attendant slowing down. The position of the light-load compensating coil may be changed by conveniently located screws and the light-load speed thus altered.

Polyphase watthour induction meters consist of two or more motor elements and one or more generator elements all mounted on a common shaft. Operation of the motor elements should be such that their combined torque for a given power will be the same on both balanced and unbalanced loads.

Frequency Meters

THESE INSTRUMENTS consist essentially of two induction voltmeter elements acting on a disk which consti-

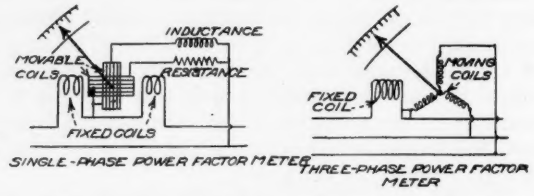


FIG. 11. TYPICAL POWER FACTOR METER CONNECTIONS

tutes the moving elements. The former tend to move the disk and the pointer shaft in opposite directions. One of the voltmeter coils is connected in series with a resistance, and the other is connected in series with a reactance, so that any change in frequency tends to change the relative strength of the two magnets and thereby cause rotation.

The disk is so shaped that as it moves, the amount of its metal under the stronger magnet becomes less than that under the weaker magnet, so that with every rotation there is a point where the torques produced by the two magnets balance and the pointer comes to rest. No control spring is employed with this movement, as all forces controlling the action are electromagnetic.

Power Factor Meters

POWER FACTOR METERS, the diagram of connections of which are shown in Fig. 11, are designed to indicate directly and accurately the power factor of alternating-current circuits. These instruments operate upon the rotating field principle, the field being produced by the current of the metered circuit in coils set at an angle to each other. Under the influence of the field is provided a movable iron vane or armature, magnetized by a coil whose current is in phase with the voltage of one phase of the circuit. As the iron vane is attracted or repelled by the rotating field of the current coils, it

will take up a position where the zero of the rotating field occurs at the same instant as the zero in its own field. Thus its position will always indicate the phase angle between the voltage and current of the circuit. The pointer attached to the armature, therefore, indicates this angle, and by marking on the scale the cosine of the angle, the power factor is read directly.

In the three-phase meter the rotating field is produced by three coils spaced 120 deg. apart and connected in the three phases of the circuit; in the two-phase meter by two current coils spaced at 90 deg.; in the single-phase meter the relative position of voltage and current coils is reversed and the rotating field is produced by means of a split-phase winding. No connection to the moving element is necessary.

Synchronizing Instruments

In one type of synchroscope a rotating field is produced by current from the bus bars passing through a split-phase winding and two angularly placed coils. In this rotating field is a revolvable iron vane, or armature, magnetized by a stationary coil connected across the lines of the incoming generator. As the armature is attracted or repelled by the rotating field of the coils connected to the bus bars, it assumes that position at which the zero of the rotating field occurs at the same instant as the zero of its own field. Thus its position at every instant indicates the phase angle between the voltage of the incoming machine and that of the bus bars. As this angle changes, due to difference in frequency, the iron vane or armature with the attached pointer rotates, and when synchronism is reached it remains stationary.

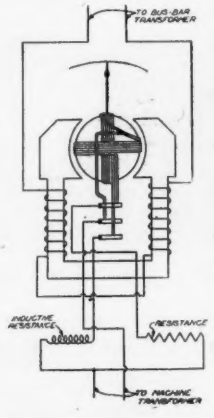


FIG. 12. SYNCHROSCOPE DIAGRAM OF CONNECTIONS.

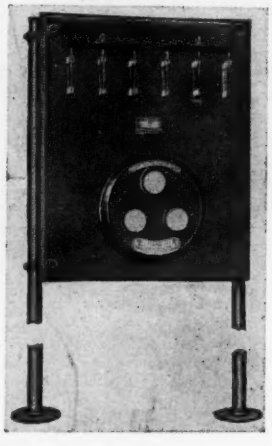


FIG. 13. GLOWER TYPE SYNCHRONISM INDICATOR.

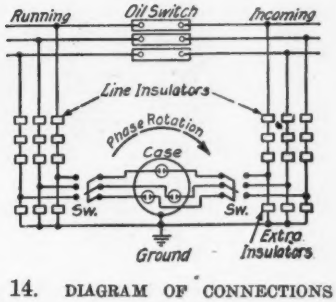


FIG. 14. DIAGRAM OF CONNECTIONS OF GLOWER TYPE SYNCHRONISM INDICATOR.

Another synchroscope, that shown in Fig. 12, is in construction not unlike a small two-phase bipolar synchronous motor with the field or stator supplied with alternating current. Two coils placed at angles of approximately 90 deg. and supplied with current from the incoming machines through the medium of collector rings constitute the armature windings; one of these coils is connected in series with a resistance, while the other is connected in series with a reactance. Due to this arrangement generating a rotating field in the armature, while the stationary field is alternating, the armature tends to assume a stationary position where the fields coincide when the alternating field passes through its maximum value. Hence the armature and its attached pointer move forward or backward at a rate corresponding to the difference of frequency, and the position when stationary depends on the phase relation. When the machines are running at the same frequency and in phase, the pointer is stationary at the marked position.

Glower-Type Synchronism Indicators

For synchronizing low-voltage machines or high-voltage machines in connection with which transformers are required for indicating or measuring purposes, lamps or electromagnetic indicators find their greatest field of usefulness. But when desired to connect together systems in which transformers are not required for indicating and measuring instruments, the equipment is comparatively inexpensive and the higher the voltage, the greater is such expense. With electrostatic synchronizers, however, no transformers are required, as they operate entirely on the charging current of the line insulators.

An indicator of the type for two-phase service is shown in Fig. 13, mounted with two three-phase disconnecting switches on a regular switchboard panel. The synchronizer proper consists of a case containing three electrostatic glowers connected to the lines to be synchronized through the medium of the disconnecting switches and strain or suspension-type insulators. The terminals of one of the glowers are connected to the same phase of running and incoming lines, while the terminals of the other two glowers are each connected to dissimilar phases.

With the incoming machine up to proper speed and voltage and ready to be synchronized, the disconnecting switches are thrown in at once, causing the glower elements to flicker in a manner not unlike that of the ordinary synchronizing lamps; the apparent direction of rotation indicates the relative speeds of the incoming and running machines. When these machines are, however, in exact synchronism, the rotation will stop and the upper glower, Fig. 14, that one, the terminals of which are connected to the same phase, will be dark, while the others will remain lighted.

Apparatus for Special Service

BOILER PERFORMANCE METERS, WATER LEVEL INDICATORS, PLANIMETERS, BRAKES AND TACHOMETERS

NUMEROUS METERS which provide the operator with information regarding the performance of steam boilers are available. One of these is illustrated in Fig. 1 and, as may be seen, not only gives the rate of steam output, but also shows whether or not this steam is being generated economically. It does this by recording on one chart both the rate of steam flow from the boiler, in red, and the rate of air flow through the furnace, in blue. When the best possible economy is being obtained, these two pens travel along the same path and record like readings at any rate of output. When the air flow pen reads more than the steam flow pen there is an excess of air passing through the fire with consequent loss of heat in the flue gases,

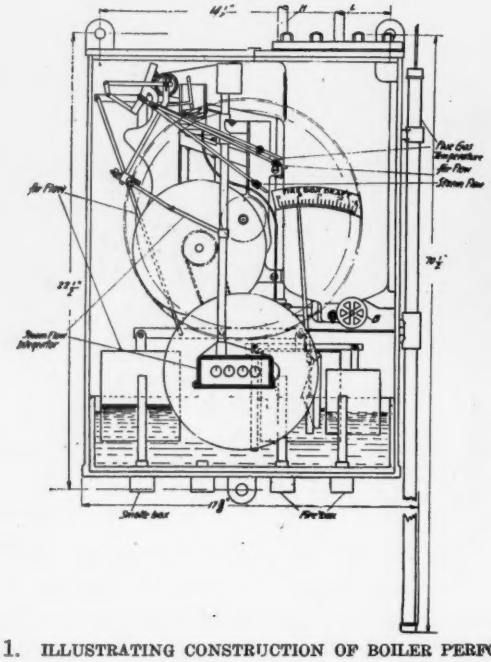


FIG. 1. ILLUSTRATING CONSTRUCTION OF BOILER PERFORMANCE METER

and when the air flow pen reads less than the steam flow there is a deficiency of air passing through the furnace, with resulting loss of heat.

The instrument is also equipped with a flue gas temperature recorder which has a bulb extending entirely across the path of the gases where they are leaving the boiler heating surface, thus providing an average temperature reading and, together with the steam and air flow readings, a check upon the condition of the boiler heating surface and baffles.

Nitrogen is used in the recorder bulb, which is made of 1½-in. seamless steel tubing, having ⅛-in. walls. This is connected by means of a ⅛-in. copper tube to a mercury U tube having one end open to the atmosphere in a reservoir, which carries a float. This float is attached directly to a pivoted yoke which carries the recorder pen.

Operation of the steam flow recorder is by means of the differential pressure across a Monel metal orifice inserted between a pair of existing pipe flanges in the steam pipe between the boiler and header. The air flow recorder employs the same basic principle and is operated by a pressure difference which varies with the rate of flow. Drop in pressure between the fire box and uptake is applied to the opposite side of an oil-sealed bell suspended from a knife edge on a beam, which is also supported on knife edges, and carries a displacing member of variable cross-sectional area immersed in mercury. Increase in rate of gas flow is accompanied by a greater pressure difference which, acting on the bell, produces motion of the beam, thereby drawing the displacing member out of the mercury reservoir. This moves until its changes in buoyancy balances the force produced by the pressure difference on the bell.

Adjustment of the air flow mechanism is made for

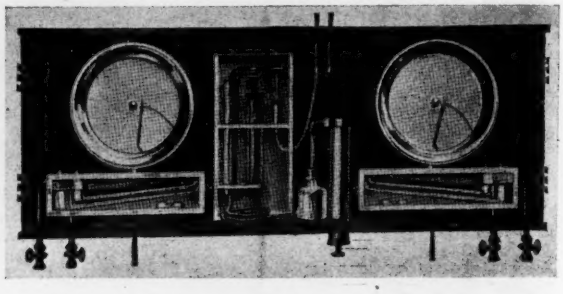


FIG. 2. BOILER INSTRUMENT CASE CONTAINING ORSAT APPARATUS, FLUE GAS THERMOMETERS AND DUPLEX DRAFT GAGES

each individual boiler and is based upon actual tests involving flue-gas analysis, draft and temperature readings, in addition to observation of the fuel bed and flame.

Where individual instruments are employed it is frequently desirable to assemble these upon a single panel or, as shown in Fig. 2, within a case, this arrangement being particularly well adapted for use in connection with a battery of two boilers. The equipment comprises two recording flue gas thermometers, two duplex draft gages, a single chamber Orsat and a gas suction pump.

WATER LEVEL INDICATORS AND RECORDERS

SHOWN IN Fig. 3 is a device designed to indicate and record the height of water in a tank or cistern, or the change of level. The bell-shaped air chamber is placed at the bottom, or any other predetermined point in the tank or reservoir. As the air in the air chamber cannot escape, it is compressed according to the depth of the liquid in the tank or the height of water level above the air chamber. The corresponding pressure is transmitted through the connecting tube to the gage and a graphic record of the height of the liquid is produced on the chart.

When installed in rivers, canals, etc., where currents exist, the air chamber should be protected by enclosing it in a box open at the top. Where the water level variations in a tank are slight, and when records showing such variations only are desired the air chamber can be mounted on a bracket slightly below the lowest water level, under which conditions, however, a chart with lower graduations must be used.

These instruments are adapted for measuring and recording height of water up to 30 ft. and variations in level as slight as 1/10 in.

Planimeters

For purposes of record and to secure test data, the average readings of recording instrument charts are frequently desired. These may readily be obtained by the use of the radial planimeter, shown in Fig. 4. The hub upon which the chart is centered while operating slides back and forth in the slot in which it is located; this slot is parallel to the axis of the integrating wheel, the diameter of which is such that the reading for a

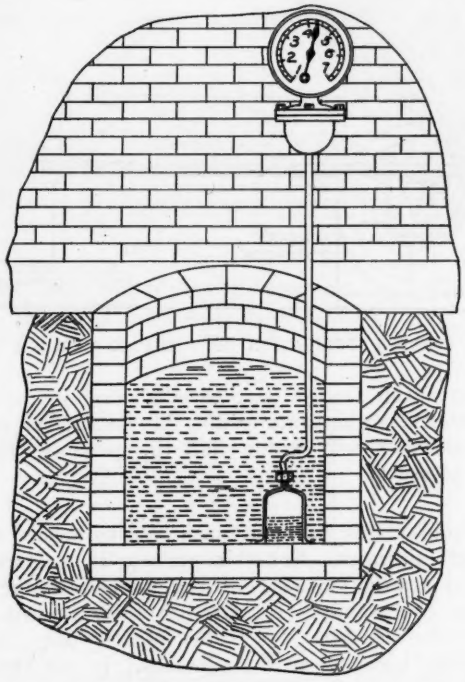


FIG. 3. WATER LEVEL INDICATOR AND MODE OF INSTALLATION

complete revolution of the chart must be divided by 24 to give the average radius in inches. For this reason the time intervals must be expressed in terms of 24 hr. for one revolution; that is, a trace covering 90 deg. on a one-hr. 24-hr. or any chart would have a time interval of $(90 \div 360) \times 24$, or 6.

To operate the instrument, slide the chart under the integrating wheel and center it in the sliding hub. Then mark a starting point on the record and when this is directly under the black tracing spot read the integrating wheel and vernier; revolve the chart clockwise, at the same time sliding back and forth so that the black tracing spot at the center of the glass is always kept directly over the record. Subtract the first reading from the final reading of the integrating wheel and vernier.

The chart is easily turned and moved with a rubber tipped pencil, resting the hand on the base of the planimeter in the manner indicated in Fig. 4.

The axis of the integrating wheel must be parallel to the slot which guides the hub upon which the chart is centered. To test this adjustment draw a diameter across the chart, center the chart in the hub and trace along this straight line from the zero or base circle to the outer circle of the chart. The integrating wheel should not revolve.

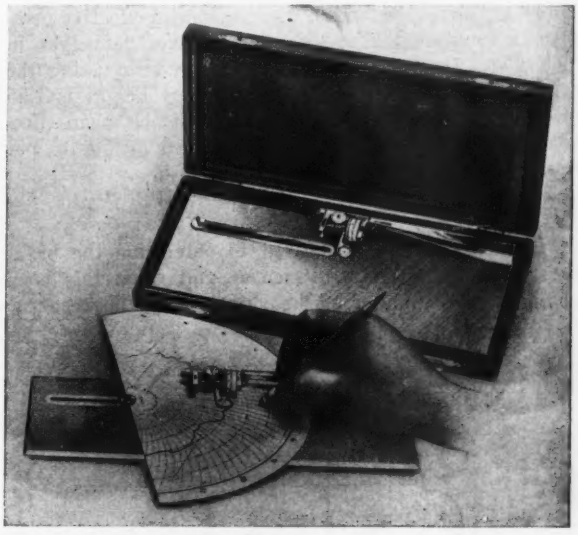


FIG. 4. A RADIAL PLANIMETER AND HOW USED

The constant for any particular instrument represents the distance from the point where the plane of the integrating wheel cuts the center line of the slot to the black tracing spot in the glass.

To determine the constant trace a series of concentric circles of known radii and find the mean radius of each circle. The difference between the radius determined from the planimeter readings and actual radii of the circles in linear inches will give a series of values of the instrument constant. Use the mean of these values.

When the radii of arcs in linear inches are larger than values obtained by the planimeter the constant is to be added to the instrument readings. If the reverse condition holds the constant is negative and should be subtracted.

Irregular areas may best be measured by means of an Amsler planimeter, a general outline of which is shown in Fig. 5. Essentially this instrument consists of a fixed arm pivoted at O to a tracing arm which carries a small graduated wheel.

With the tracing point placed at point A on the diagram A B C D, note the reading of the graduated wheel. Then cause the tracing point to follow path A B C D in a clockwise direction until point A is again reached, when the reading of the wheel is again noted. The difference between these readings will be the area of the diagram generally expressed in square inches, although in some instruments which are espe-

cially designed for use with indicator cards it is possible to obtain a direct reading of the mean effective pressure in pounds per square inch.

Where planimeters are not available irregular areas, such as indicator cards, may readily be computed mathematically by the method of ordinates. Perpendicular to the atmospheric line erect a number of ordinates, as, for instance, 10, equal distances apart. Midway between these draw parallel lines extending from the top to the bottom of the diagram; measure these lines in inches, add their total lengths and by dividing by the number of lines drawn obtain the average height of the card. The area of the card is then equal to this average height times the length, while the mean effective pressure is equal to the product of the average height in inches and the scale of spring employed in taking the card. Where, for example, the average height is 1.25 in. and the scale of spring used was 40, the mean effective pressure is equal to 1.25 times 40 or 50 lb. per square inch.

Brakes

Occasionally it is desired to determine the brake horsepower of some prime mover and when this is of comparatively small size the Prony brake may be em-

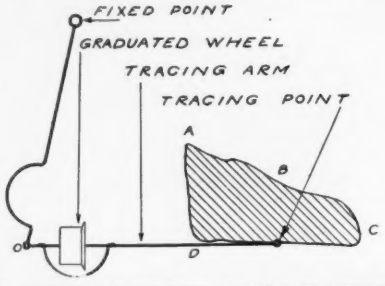


FIG. 5. ELEMENTS OF THE AMSLER PLANIMETER

ployed to advantage. Application of this device to an electric motor is shown in Fig. 6. If not already so provided, the machine shaft is fitted with a pulley having a diameter the same as that of the pitch of the pinion or gear removed. Adjust the load as desired and note speed of revolving member in revolutions per minute, and reading of scale when in a state of balance. Dividing product of horizontal distance L from center of shaft to point of application on scale platform, scale reading in pounds, number of revolutions per minute of rotating member and 6.2832, by 33,000 will give number of horsepower developed.

The electric generator, especially when direct-connected to the prime mover, affords an accurate means of determining the output of high-speed engines and turbines. In the case of direct-current generators the engine or turbine output is equal to the quotient obtained by dividing the product of the number of volts and number of amperes by the product of the efficiency of the generator under the particular load and speed the machine is operating, and 746. When single and two phase alternating-current is used, the numerator must in turn be multiplied by the power factor expressed as a decimal, and where three-phase machines are used further multiplication by the square root of 3 is necessary. Uniform load must be maintained on the generator and if sufficient lamps and motors are not available to provide this a water rheostat may be used.

Speed Indicators

The simplest form of speed indicator, the hand speed counter, consists of a small steel pointed shaft carrying at one end a rubber tip to prevent slipping, and geared to operate a counting device. This instrument is best suited for speeds ranging from 200 to 2000 r.p.m.

For such work as recording the number of strokes of a reciprocating pump or of a slow-speed steam engine the continuous speed counter or cyclometer is useful. In this device a series of gears operates a set of disks indicating by successive digits total revolutions.

The tachometer provides instantaneous indications of speed and may be of either the indicating or recording type. In one form centrifugal force is employed. Attached to the spindle transmitting the speed are two linked weights which, although under the restraint of a spring move outward, the degree of travel being dependent upon the speed. These weights actuate a pointer traveling over a graduated scale.

A tachometer particularly well adapted to high-speed work is that employing a magneto type of electric

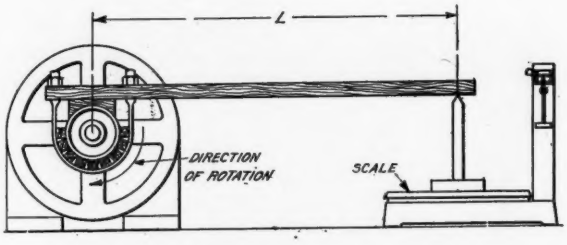


FIG. 6. APPLICATION OF THE PRONY BRAKE

generator which indicates speed by a suitably graduated voltmeter. For accurate results this instrument should be attached directly to the shaft the speed of which is to be measured.

Liquid oxygen has been much used by airmen flying at high altitudes. For this purpose it is stored in vacuum vessels provided with a mechanism for controlling the evaporation, and with tubes leading to a mouthpiece through which the aviator may inhale. There are three types of mechanism. In the first, the liquid is heated electrically; in the second, the evaporation is promoted and controlled by thermal conduction through a rod of copper or aluminum in the liquefied gas; in the third the liquid is siphoned out into an evaporating chamber, from which the gas is conducted through tubes—to bring it to air-temperature—to the airman's mouth, the rate of evaporation being controlled by adjusting the conical stopcock through which the gas is passed.

Liquid air is stored in spherical metallic vacuum vessels holding from 5 to 30 gallons, the high vacuum required being maintained by keeping absorbent charcoal cooled to the temperature of the liquefied gas, in a chamber attached to the lowest part of the external wall of the inner vessel, whereby the annular space is highly exhausted. These vessels are durable, and the rate of loss from the largest does not exceed 5 per cent per day.—Compressed Air Magazine.

Reference Tables and Charts

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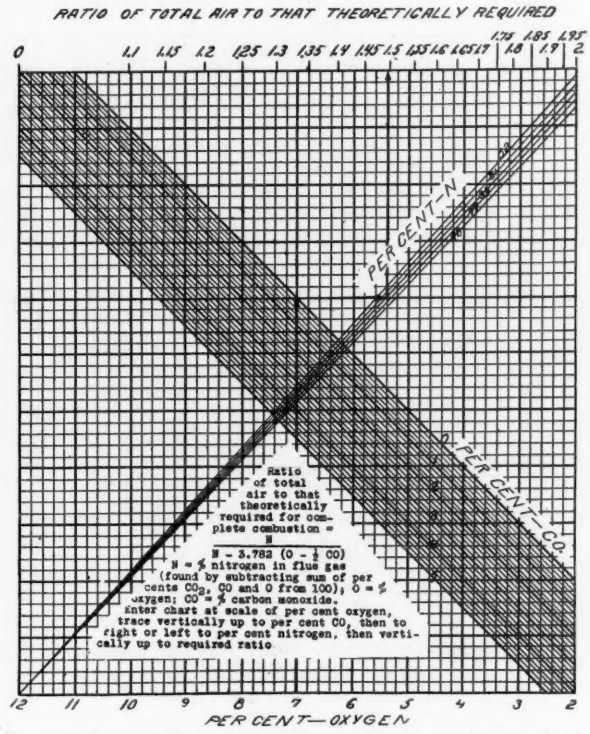

RATIO OF TOTAL AIR TO THAT THEORETICALLY REQUIRED
PER CENT—OXYGEN
PER CENT—N
PER CENT—CO
Ratio of total air to that theoretically required for complete combustion = N / N - 3.782 (O - ½ CO)
N = % nitrogen in flue gas (found by subtracting sum of per cents CO2, CO and O from 100); O = % oxygen; CO = % carbon monoxide.
Enter chart at scale of per cent oxygen, trace vertically up to per cent CO, then to right or left to per cent nitrogen, then vertically up to required ratio

1. RATIO OF TOTAL AIR USED TO THAT THEORETICALLY REQUIRED FOR COMPLETE COMBUSTION CALCULATED FROM FLUE GAS ANALYSIS

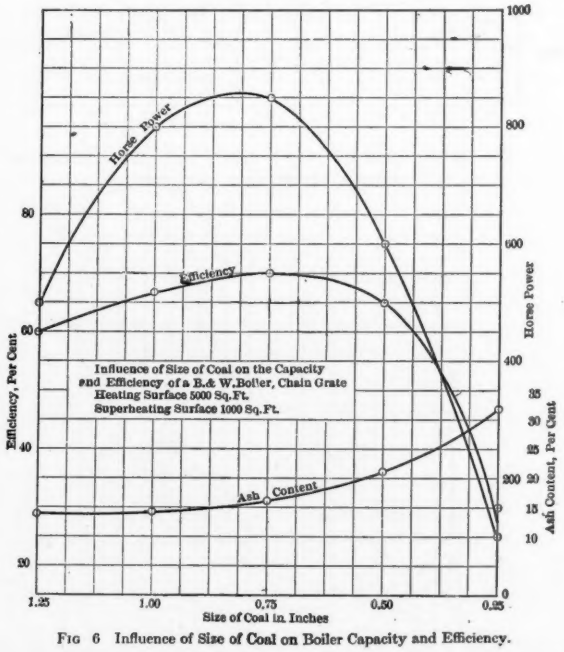
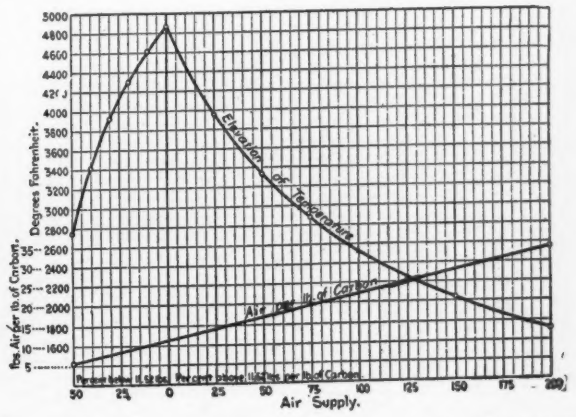
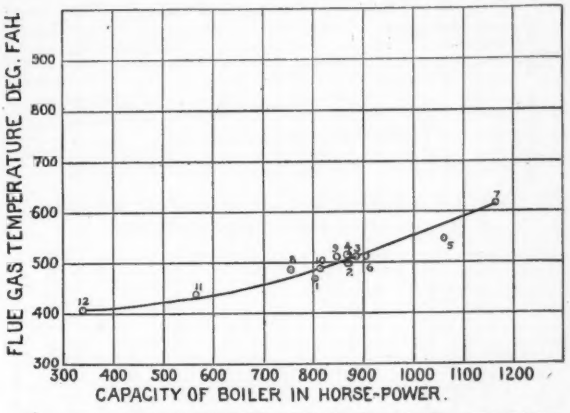

Horse Power
Epiciency
Ash Content
Influence of Size of Coal on the Capacity and Efficiency of a B.& W.Boiler, Chain Grate Heating Surface 5000 Sq.Ft. Superheating Surface 1000 Sq.Ft.
Efficiency, Per Cent
Horse Power
Ash Content, Per Cent
Size of Coal in Inches

Fig 6 Influence of Size of Coal on Boiler Capacity and Efficiency.

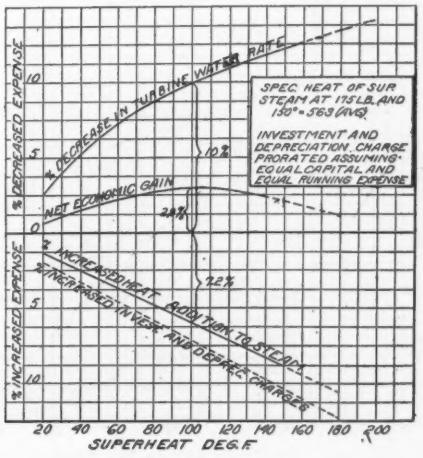
2. INFLUENCE OF SIZE OF COAL ON BOILER CAPACITY AND EFFICIENCY—GEBHARDT



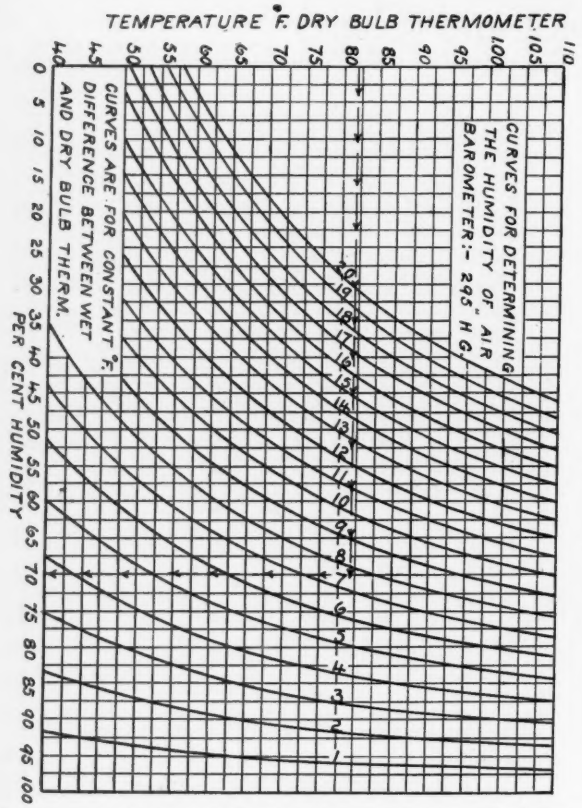
3. MAXIMUM THEORETICAL TEMPERATURE OF A FURNACE



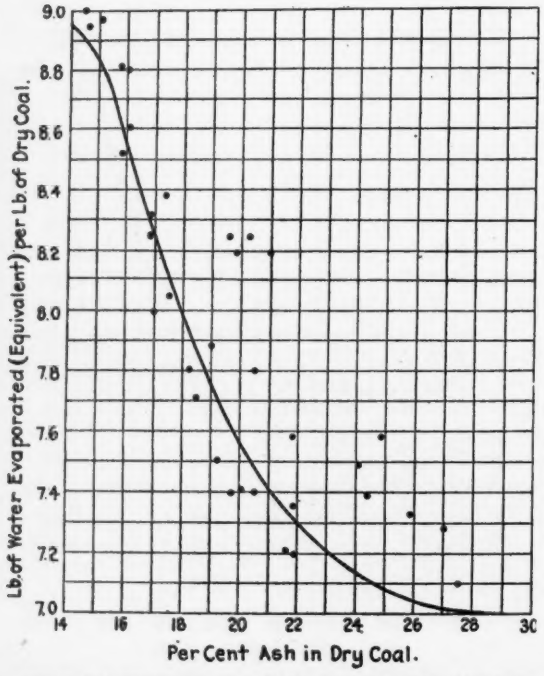
4. RELATION BETWEEN BOILER CAPACITY AND FLUE TEMPERATURE—HARRINGTON


% DECREASED EXPENSE
% INCREASED EXPENSE
% DECREASE IN TURBINE WATER RATE
NET ECONOMIC GAIN
% INCREASED INVEST. ADDITION TO STEAM
% INCREASED INVEST. AND DEGREE F. FOR RATE
SPEC. HEAT OF SUR STEAM AT 175 LB. AND 150° = .563 (AVG)
INVESTMENT AND DEPRECIATION CHARGE PRORATED ASSUMING EQUAL CAPITAL AND EQUAL RUNNING EXPENSE
SUPERHEAT DEG. F

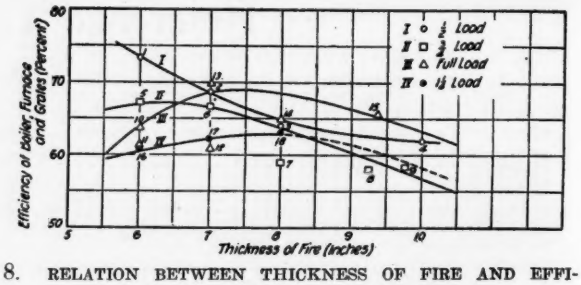
5. NET IMPROVEMENT IN PLANT EFFICIENCY WITH VARYING DEGREES OF SUPERHEAT


TEMPERATURE F. DRY BULB THERMOMETER
PER CENT HUMIDITY
CURVES ARE FOR CONSTANT DIFFERENCE BETWEEN WET AND DRY BULB THERM.
CURVES FOR DETERMINING THE HUMIDITY OF AIR BAROMETER:- 29.5" H G.

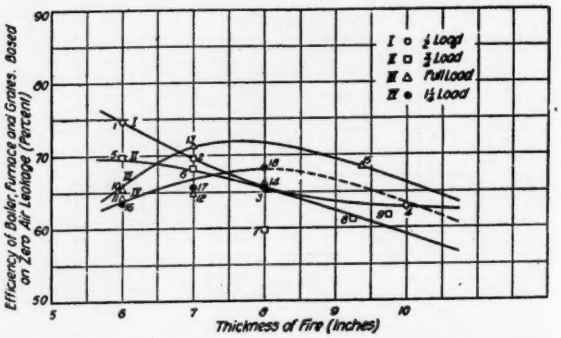
6. CURVES FOR DETERMINING HUMIDITY OF AIR FROM WET AND DRY BULB THERMOMETER



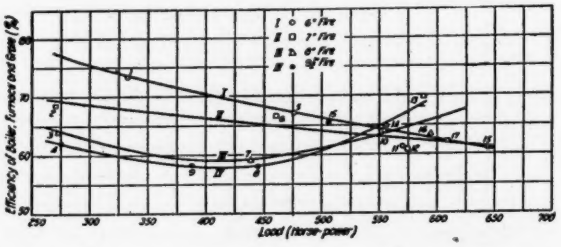
7. RELATION BETWEEN ASH CONTENT AND EVAPORATION—POLAKOV



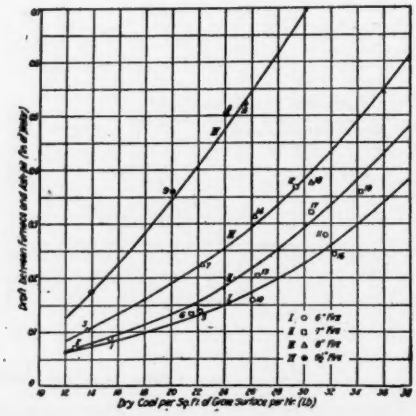
8. RELATION BETWEEN THICKNESS OF FIRE AND EFFICIENCY OF BOILER, FURNACE AND GRATE


Efficiency of Boiler, Furnace and Grate, Based on Zero Air Leakage (Percent)
Thickness of Fire (inches)
I ○ ½ Load
II □ ¾ Load
III △ Full Load
IV ● 1½ Load

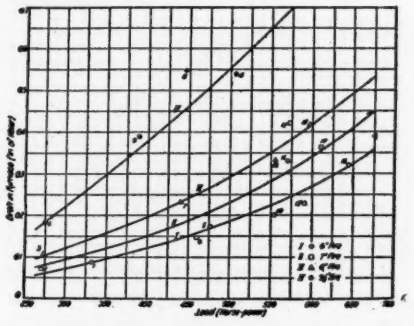
9. RELATION BETWEEN THICKNESS OF FIRE AND EFFICIENCY OF BOILER FURNACE AND GRATE BASED ON ZERO AIR LEAKAGE



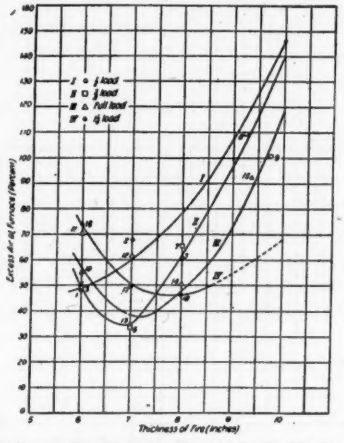
10. RELATION BETWEEN LOAD AND EFFICIENCY OF BOILER, FURNACE AND GRATE



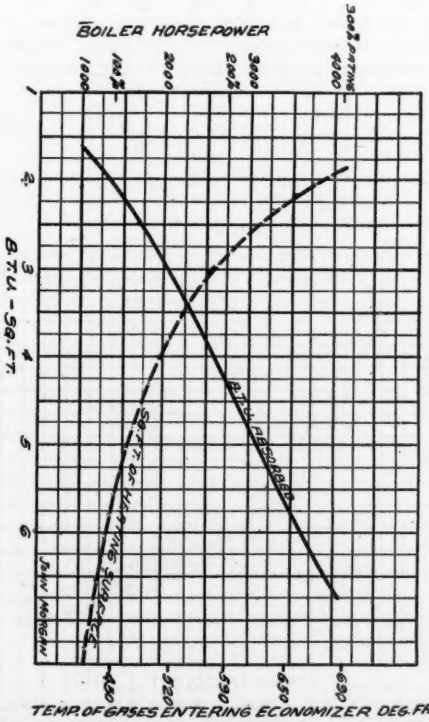
11. RELATION BETWEEN DRAFT LOSS AND COAL BURNED



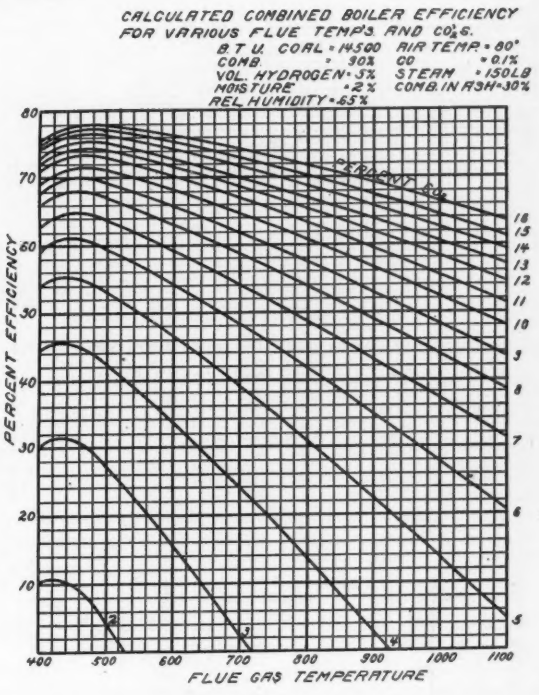
12. RELATION BETWEEN LOAD AND DRAFT IN FURNACE



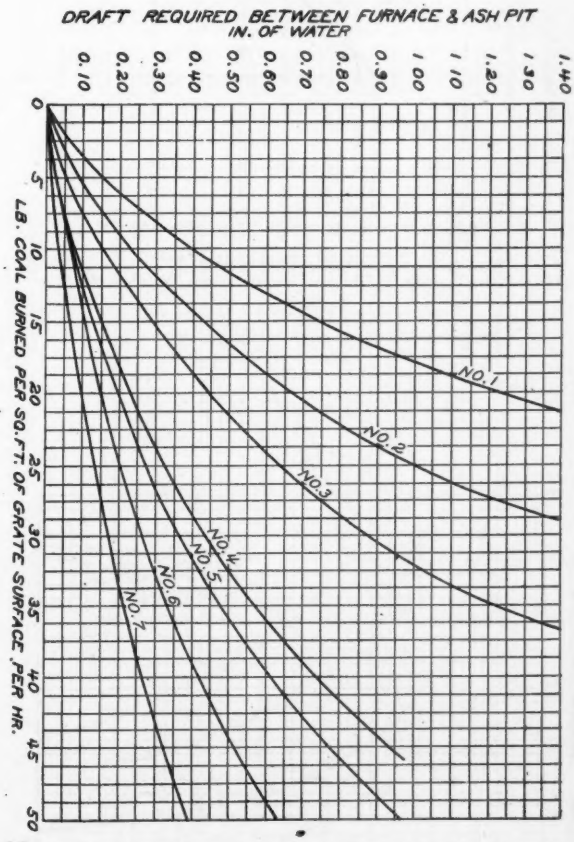
13. RELATION BETWEEN THICKNESS OF FIRE AND EXCESS AIR IN FURNACE



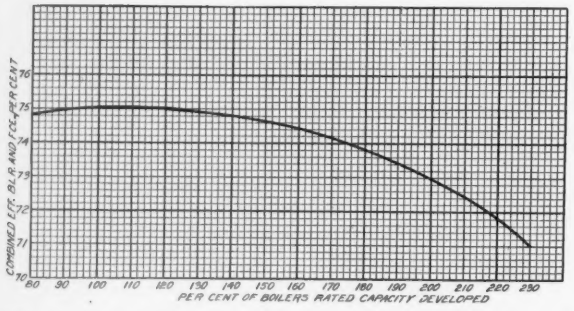
14. ECONOMIZER HEATING SURFACE PER BOILER HORSEPOWER; HEAT ABSORBED PER SQUARE FOOT PER DEGREE REDUCTION IN FLUE GAS TEMPERATURE


CALCULATED COMBINED BOILER EFFICIENCY
FOR VARIOUS FLUE TEMPS AND CO2'S.
B.T.U. COAL = 14500 AIR TEMP. = 80°
COMB. = 90% CO = 0.1%
VOL. HYDROGEN = 5% STEAM = 150 LB
MOISTURE = 2% COMB. IN ASH = 30%
REL. HUMIDITY = 65%
PERCENT EFFICIENCY
FLUE GAS TEMPERATURE

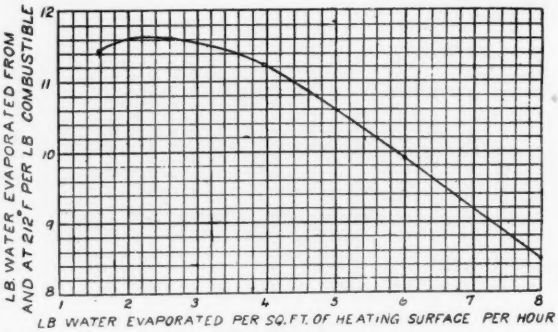
15. VARIATION OF EFFICIENCY OF BOILER WITH FLUE GAS TEMPERATURE AND CO_2



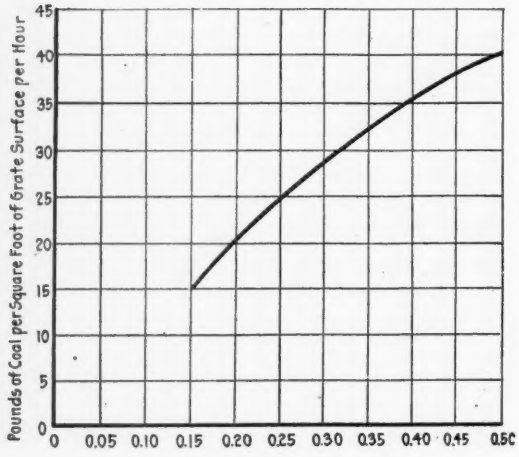
16. DRAFT REQUIRED BETWEEN FURNACE AND ASHPIT. NO. 1, ANTHRACITE BUCKWHEAT NO. 3; NO. 2, ANTHRACITE BUCKWHEAT NO. 1; NO. 3, ANTHRACITE PEA; NO. 4, CHAIN GRATE BURNING BITUMINOUS SLACK; NO. 5, RUN OF MINE SEMI-BITUMINOUS; NO. 6, BITUMINOUS SLACK; NO. 7, RUN OF MINE BITUMINOUS


COMBINED EFF. BLR. AND FDS., PER CENT
70 71 72 73 74 75 76
80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 250
PER CENT OF BOILERS RATED CAPACITY DEVELOPED

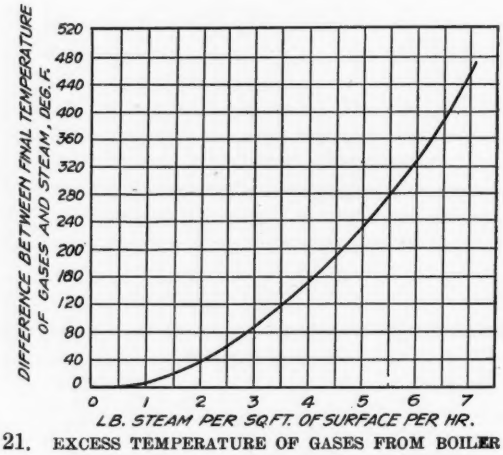
17. APPROXIMATE VARIATION OF BOILER EFFICIENCY WITH CAPACITY UNDER TEST CONDITIONS


LB. WATER EVAPORATED FROM AND AT 212° F PER LB COMBUSTIBLE
8 9 10 11 12
1 2 3 4 5 6 7 8
LB WATER EVAPORATED PER SQ. FT. OF HEATING SURFACE PER HOUR

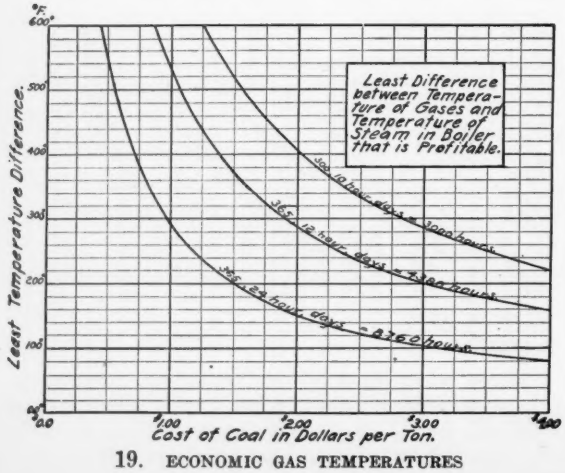
20. VARIATION IN FUEL CONSUMPTION WITH RATE OF EVAPORATION


Pounds of Coal per Square Foot of Grate Surface per Hour
0 5 10 15 20 25 30 35 40 45
0 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50
Draft Over Fire in Inches of Water

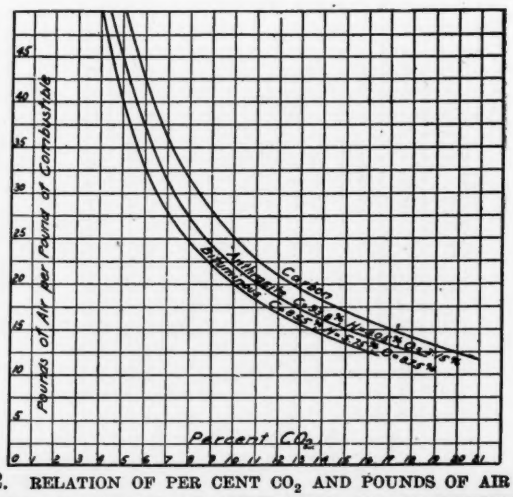
18. DRAFT REQUIRED FOR SMOKELESS COMBUSTION—MONNETT


DIFFERENCE BETWEEN FINAL TEMPERATURE OF GASES AND STEAM, DEG. F.
0 40 80 120 160 200 240 280 320 360 400 440 480 520
0 1 2 3 4 5 6 7
LB. STEAM PER SQ. FT. OF SURFACE PER HR.

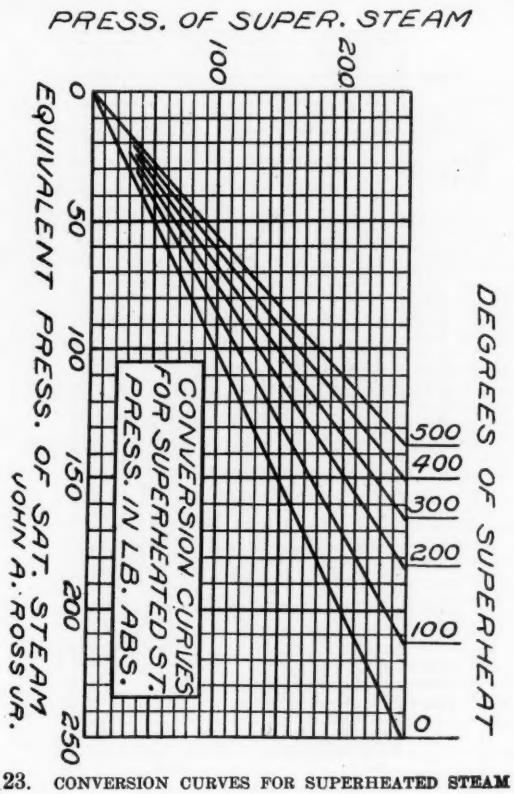
21. EXCESS TEMPERATURE OF GASES FROM BOILER AS AFFECTED BY RATE OF DRIVING—G. H. GIBSON


°F.
Least Temperature Difference.
Least Difference between Temperature of Gases and Temperature of Steam in Boiler that is Profitable.
365 10-hour days = 3650 hours
365 12-hour days = 4380 hours
365 24-hour days = 8760 hours
0 100 200 300 400
Cost of Coal in Dollars per Ton.

19. ECONOMIC GAS TEMPERATURES



22. RELATION OF PER CENT CO_2 AND POUNDS OF AIR PER POUND OF CARBON, OF ANTHRACITE AND OF BITUMINOUS



23. CONVERSION CURVES FOR SUPERHEATED STEAM

25. PERCENTAGE OF SAVING FOR EACH DEGREE OF INCREASE OF TEMPERATURE OF FEED WATER

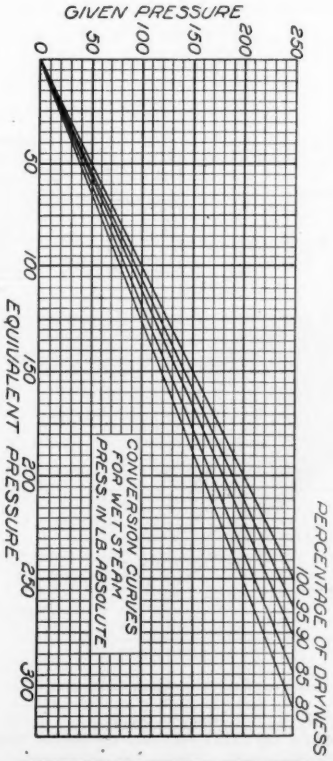
Initial Temp. of Feed.	Boiler Pressure above Atmosphere.										
	0	20	40	60	80	100	120	140	160	180	200
32	.0872	.0861	.0855	.0851	.0847	.0844	.0841	.0839	.0837	.0835	.0833
40	.0878	.0867	.0861	.0856	.0853	.0850	.0847	.0845	.0843	.0841	.0839
50	.0886	.0875	.0868	.0864	.0860	.0857	.0854	.0852	.0850	.0848	.0846
60	.0894	.0883	.0876	.0872	.0867	.0864	.0862	.0859	.0856	.0855	.0853
70	.0902	.0890	.0884	.0879	.0875	.0872	.0869	.0867	.0864	.0862	.0860
80	.0910	.0898	.0891	.0887	.0883	.0879	.0877	.0874	.0872	.0870	.0868
90	.0919	.0907	.0900	.0895	.0888	.0887	.0884	.0883	.0879	.0877	.0875
100	.0927	.0915	.0908	.0903	.0899	.0895	.0892	.0890	.0887	.0885	.0883
110	.0936	.0923	.0916	.0911	.0907	.0903	.0900	.0898	.0895	.0893	.0891
120	.0945	.0932	.0925	.0919	.0915	.0911	.0908	.0906	.0903	.0901	.0899
130	.0954	.0941	.0934	.0928	.0924	.0920	.0917	.0914	.0912	.0909	.0907
140	.0963	.0950	.0943	.0937	.0932	.0929	.0925	.0923	.0920	.0918	.0916
150	.0973	.0959	.0951	.0946	.0941	.0937	.0934	.0931	.0929	.0926	.0924
160	.0982	.0968	.0961	.0955	.0950	.0946	.0943	.0940	.0937	.0935	.0933
170	.0992	.0978	.0970	.0964	.0959	.0955	.0952	.0949	.0946	.0944	.0941
180	.1002	.0988	.0981	.0973	.0969	.0965	.0961	.0958	.0955	.0953	.0951
190	.1012	.0998	.0989	.0983	.0978	.0974	.0971	.0968	.0964	.0962	.0960
200	.1022	.1008	.0999	.0993	.0988	.0984	.0980	.0977	.0974	.0972	.0969
210	.1033	.1018	.1009	.1003	.0998	.0994	.0990	.0987	.0984	.0981	.0979
220	.....	.1029	.1019	.1013	.1008	.1004	.1000	.0997	.0994	.0991	.0989
230	.....	.1039	.1031	.1024	.1018	.1012	.1010	.1007	.1003	.1001	.0999
240	.....	.1050	.1041	.1034	.1029	.1024	.1020	.1017	.1014	.1011	.1009
250	.....	.1062	.1052	.1045	.1040	.1035	.1031	.1027	.1025	.1022	.1019

Multiply the factor in the table corresponding to any given initial temperature of feed water and boiler pressure by the total rise in feed-water temperature; the product will be the percentage of saving.

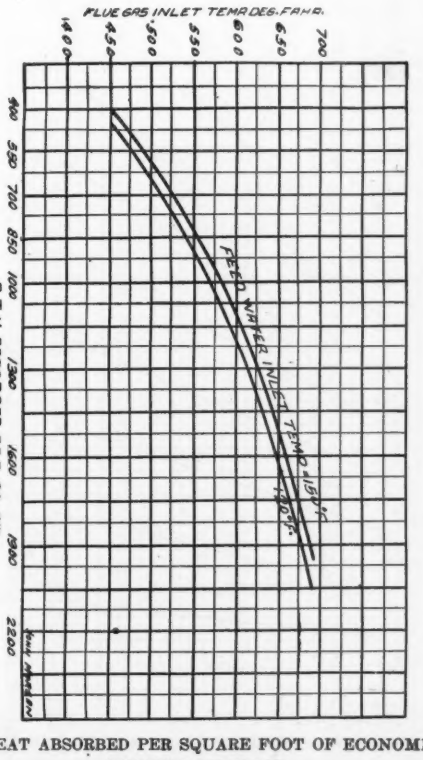
26. TEMPERATURE OBTAINABLE IN OPEN FEED WATER HEATER, CONDENSING PLANT—DATA

Per Cent of Total Steam Used by Auxiliaries.	Initial Temperature of Feed Water, Degrees F.									
	40	50	60	70	80	90	100	110	120	130
2	60.1	69.9	79.7	89.5	99.4	109.2	119.0	128.8	138.7	148.5
3	69.9	79.6	89.3	99.1	108.8	118.6	128.3	138.0	147.8	157.5
4	79.5	89.1	98.8	108.5	118.1	127.8	137.4	147.1	156.7	166.4
5	89.0	98.5	108.1	117.7	127.2	136.8	146.4	155.9	165.5	175.1
6	98.3	107.7	117.2	126.7	136.2	145.7	155.2	164.7	174.2	183.6
7	107.4	116.8	126.2	135.6	145.0	154.4	163.8	173.2	182.5	192.1
8	116.4	125.7	135.0	144.4	153.7	163.0	172.4	181.3	191.0	200.3
9	125.2	134.5	143.7	153.0	162.2	171.5	180.7	190.0	199.2	208.5
10	133.3	143.1	152.3	161.4	170.6	179.8	189.0	198.1	207.3	212.0
11	142.2	151.2	160.7	169.7	178.9	188.2	197.0	206.2	212.0*	212.0*
12	150.9	159.9	168.9	177.9	187.0	196.0	205.0	212.0*	212.0*	212.0*

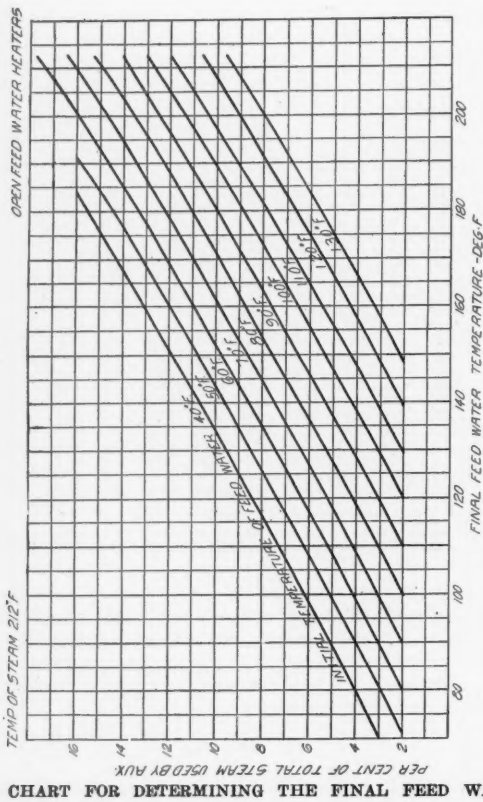
* All of the steam not used.



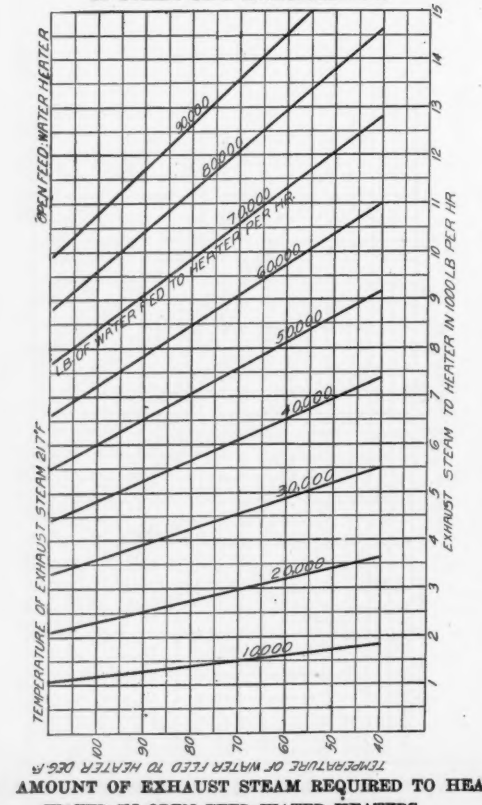
24. CONVERSION CURVES FOR WET STEAM



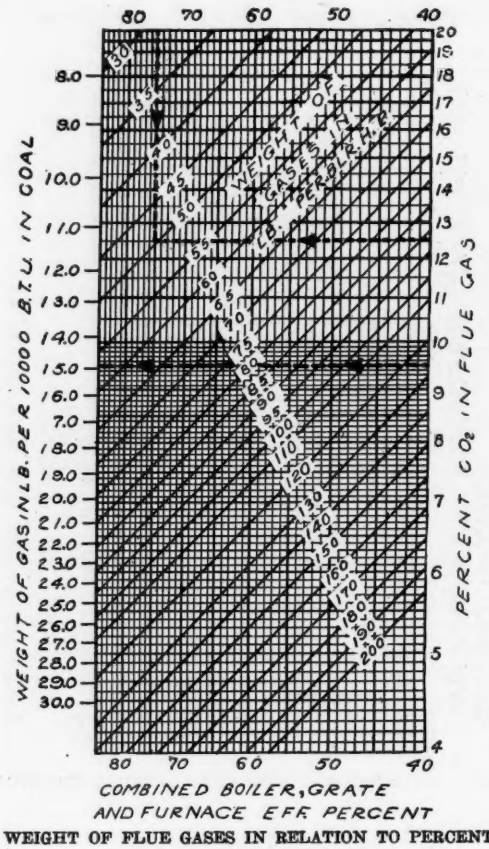
27. HEAT ABSORBED PER SQUARE FOOT OF ECONOMIZER HEATING SURFACE


OPEN FEED WATER HEATERS
TEMP OF STEAM 212°F
FINAL FEED WATER TEMPERATURE-DEG.F
INITIAL TEMPERATURE OF FEED WATER
PER CENT OF TOTAL STEAM USED BY AUX

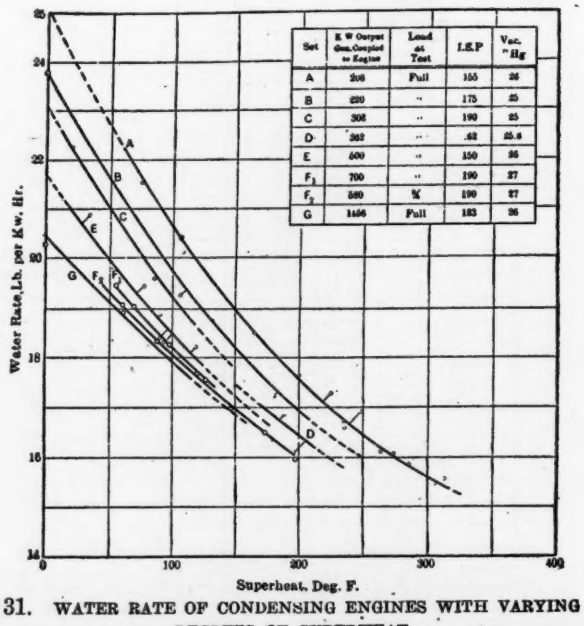
28. CHART FOR DETERMINING THE FINAL FEED WATER TEMPERATURE IN OPEN FEED WATER HEATERS FROM THE INITIAL TEMPERATURE AND PER CENT OF STEAM USED IN AUXILIARIES


OPEN FEED WATER HEATER
LB OF WATER FED TO HEATER PER HR
TEMPERATURE OF EXHAUST STEAM 217°F
EXHAUST STEAM TO HEATER IN 1000 LB PER HR
TEMPERATURE OF WATER FEED TO HEATER DEG.F

29. AMOUNT OF EXHAUST STEAM REQUIRED TO HEAT WATER IN OPEN FEED WATER HEATERS

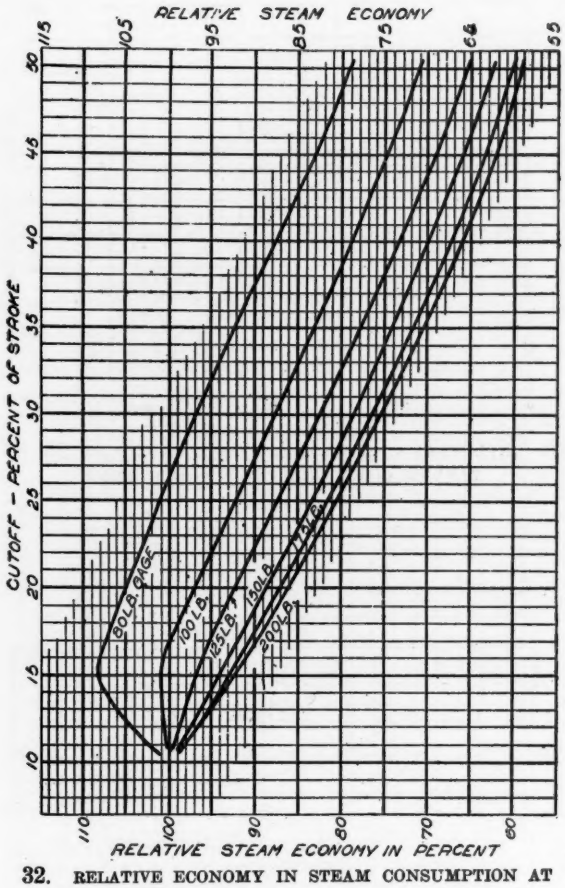


30. WEIGHT OF FLUE GASES IN RELATION TO PERCENTAGE OF CO_2, COMBINED BOILER EFFICIENCY AND BOILER HORSEPOWER

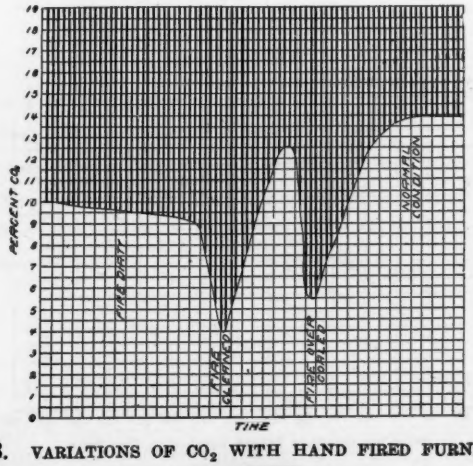


Set	K. W. Output Gen. Coupled to Engine	Load at Test	I.H.P.	Vac. "Hg
A	208	Full	155	26
B	220	"	175	25
C	308	"	190	25
D	302	"	182	25.8
E	300	"	150	26
F_1	700	"	190	27
F_2	880	"	190	27
G	1464	Full	183	26

31. WATER RATE OF CONDENSING ENGINES WITH VARYING DEGREES OF SUPERHEAT



32. RELATIVE ECONOMY IN STEAM CONSUMPTION AT VARIOUS CUT-OFFS, BACK PRESSURE ZERO POUNDS GAGE



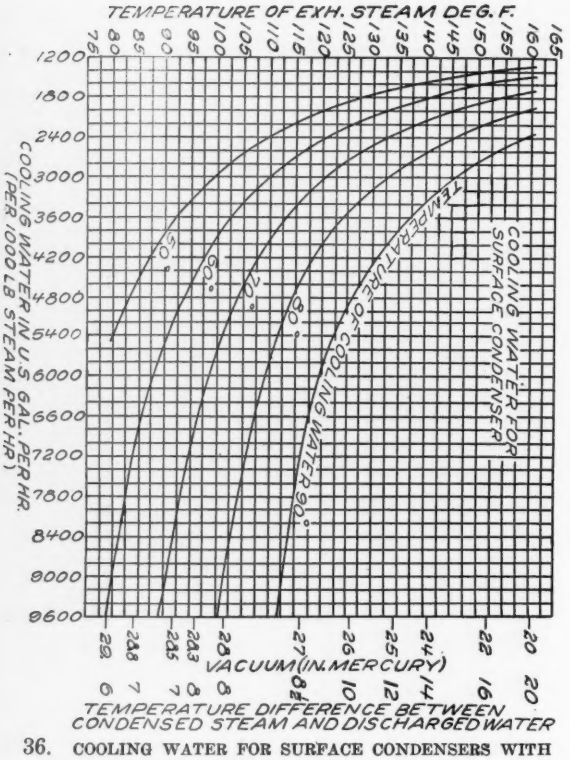
33. VARIATIONS OF CO_2 WITH HAND FIRED FURNACE CONDITIONS

34. POUNDS INJECTION WATER REQUIRED PER POUND OF STEAM, JET CONDENSERS

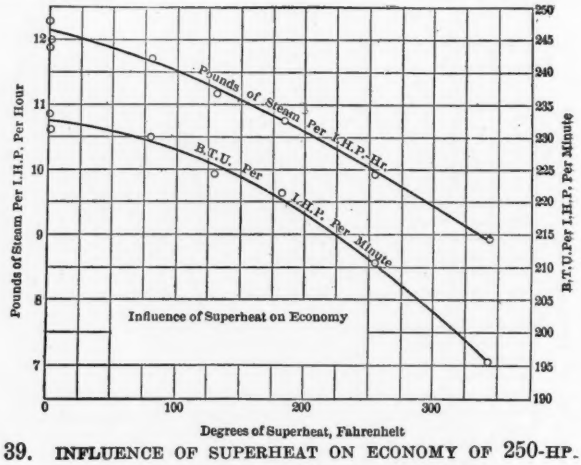
Hot Well Temp. Deg. F.	Initial Temp. Injection Water Deg. F.	Vacuum, Inches Mercury						
		23	24	26	27	28	29	29.5
120	35	12.2	12.1	12.0	11.9	11.9	11.8	11.6
	40	12.9	12.8	12.7	12.7	12.6	12.5	12.4
	50	14.8	14.7	14.6	14.5	14.4	14.3	14.1
	60	17.3	17.1	17.0	16.9	16.8	16.7	16.5
	70	20.7	20.6	20.4	20.3	20.2	20.1	19.8
	80	25.9	25.6	25.5	25.4	25.3	25.0	24.8
	90	34.6	34.3	34.0	33.9	33.7	33.4	33.1
	100	51.8	51.5	51.1	50.9	50.6	50.1	49.6
	110	103.5	103.0	102.2	101.8	101.2	100.2	99.3
110	35	13.9	13.8	13.7	13.7	13.6	13.5	13.2
	40	14.9	14.8	14.7	14.6	14.6	14.4	14.3
	50	17.4	17.3	17.2	17.1	17.0	16.8	16.7
	60	20.9	20.8	20.6	20.5	20.4	20.2	20.0
	70	26.1	26.0	25.8	25.7	25.5	25.3	25.0
	80	34.8	34.6	34.4	34.2	34.1	33.7	33.4
	90	52.2	52.0	51.6	51.4	51.1	50.6	50.1
	100	104.5	104.0	103.2	102.8	102.3	101.2	100.3
100	35	16.2	16.1	16.0	15.9	15.8	15.7	15.5
	40	17.5	17.5	17.3	17.3	17.2	17.0	16.9
	50	21.1	21.0	20.8	20.7	20.6	20.4	20.2
	60	26.3	26.2	26.0	25.9	25.8	25.5	25.3
	70	35.1	35.0	34.7	34.6	34.4	34.0	33.7
	80	52.7	52.5	52.1	51.9	51.6	51.1	50.6
	90	105.5	105.0	104.2	103.8	103.3	102.2	101.3
90	35	19.3	19.2	19.0	19.0	18.9	18.7	18.6
	40	21.3	21.2	21.0	20.9	20.8	20.6	20.4
	50	26.6	26.5	26.3	26.2	26.0	25.8	25.5
	60	35.5	35.3	35.0	34.9	34.7	34.4	34.1
	70	53.2	53.0	52.6	52.4	52.1	51.6	51.1
	80	106.6	106.0	105.2	104.8	104.3	103.2	102.3
80	35	23.9	23.7	23.6	23.5	23.4	23.1	22.9
	40	26.8	26.7	26.5	26.4	26.3	26.0	25.7
	50	35.8	35.6	35.4	35.2	35.1	34.7	34.4
	60	53.7	53.5	53.1	52.9	52.6	52.1	51.6
	70	107.5	107.0	106.2	105.8	105.3	104.2	103.3
70	35	31.0	30.8	30.6	30.5	30.3	30.0	29.8
	40	36.1	36.0	35.7	35.6	35.4	35.0	34.7
	50	54.2	54.0	53.6	53.4	53.1	52.6	52.1
	60	108.5	108.0	107.2	106.8	106.3	105.2	104.3

35. POUNDS CIRCULATING WATER REQUIRED PER POUND OF STEAM, SURFACE CONDENSERS

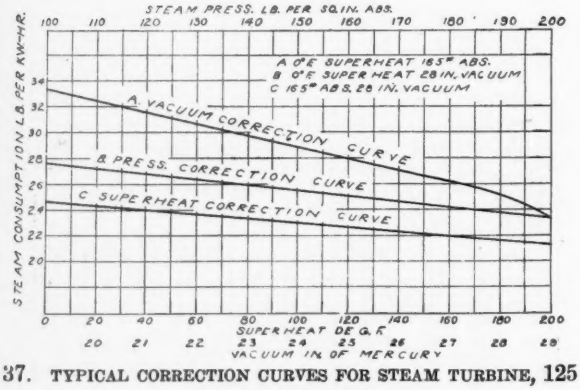
Temp. of Cooling Water, Deg. F.	Temp. of Discharge Water, Deg. F.	Vacuum, Inches Mercury						
		23	24	26	27	28	29	29.5
35	80	22.3	22.5	22.6	22.8	22.9	23.2	23.5
	90	18.3	18.3	18.4	18.5	18.8	19.0	19.2
	100	15.4	15.5	15.6	15.8	15.9	16.1	16.3
	110	13.5	13.6	13.6	13.6	13.7	13.9	14.1
	120	11.8	11.9	12.0	12.0	12.1	12.3	12.4
	130	10.5	10.6	10.7	10.8	10.8	11.0	11.1
	140	9.5	9.6	9.7	9.8	9.8	9.9	10.0
40	80	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	90	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	100	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	110	14.3	14.4	14.5	14.6	14.7	14.9	15.1
	120	12.5	12.6	12.7	12.8	12.9	13.0	13.2
	130	11.1	11.2	11.3	11.4	11.4	11.6	11.7
	140	10.0	10.1	10.2	10.2	10.3	10.4	10.5
50	80	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	90	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	100	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	110	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	120	14.3	14.4	14.5	14.6	14.7	14.9	15.1
	130	12.5	12.6	12.7	12.8	12.9	13.0	13.2
	140	11.1	11.2	11.3	11.4	11.4	11.6	11.7
60	80	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	90	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	100	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	110	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	120	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	130	14.3	14.4	14.5	14.6	14.7	14.9	15.1
	140	12.5	12.6	12.7	12.8	12.9	13.0	13.2
70	80	100.6	101.2	102.1	102.7	103.4	104.7	105.8
	90	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	100	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	110	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	120	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	130	16.7	16.8	17.0	17.1	17.2	17.4	17.6
	140	14.3	14.4	14.5	14.6	14.7	14.9	15.1
80	90	100.6	101.2	102.1	102.7	103.4	104.7	105.8
	100	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	110	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	120	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	130	20.1	20.2	20.4	20.5	20.6	20.9	21.1
	140	16.7	16.8	17.0	17.1	17.2	17.4	17.6
90	100	100.6	101.2	102.1	102.7	103.4	104.7	105.8
	110	50.3	50.6	51.0	51.3	51.7	52.3	52.9
	120	33.5	33.7	34.0	34.2	34.4	34.9	35.2
	130	25.1	25.3	25.5	25.6	25.8	26.1	26.4
	140	20.1	20.2	20.4	20.5	20.6	20.9	21.1


TEMPERATURE OF EXH. STEAM DEG. F.
COOLING WATER IN U.S. GAL. PER HR. (PER 1000 LB STEAM PER HR.)
50°
60°
70°
80°
90°
TEMPERATURE OF COOLING WATER
COOLING WATER FOR SURFACE CONDENSER
VACUUM (IN. MERCURY)
TEMPERATURE DIFFERENCE BETWEEN CONDENSED STEAM AND DISCHARGED WATER

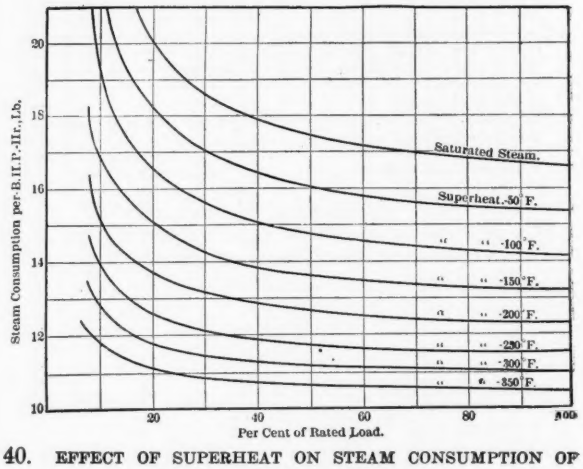
36. COOLING WATER FOR SURFACE CONDENSERS WITH VARYING TEMPERATURES AND VACUUM


Pounds of Steam Per I.H.P.-Hr.
B.T.U. Per I.H.P. Per Minute
Influence of Superheat on Economy
Pounds of Steam Per I.H.P. Per Hour
B.T.U. Per I.H.P. Per Minute
Degrees of Superheat, Fahrenheit

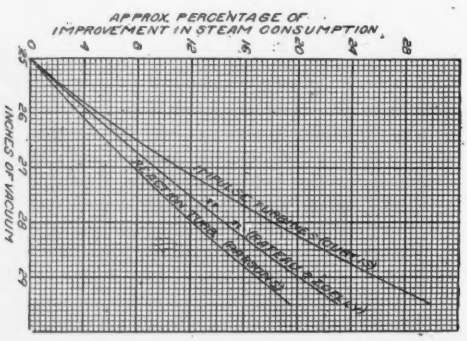
39. INFLUENCE OF SUPERHEAT ON ECONOMY OF 250-HP. TANDEM COMPOUND ENGINE—GEBHARDT


STEAM PRESS. LB. PER SQ. IN. ABS.
A 0°F SUPERHEAT 185# ABS.
B 0°F SUPERHEAT 28 IN. VACUUM
C 185# ABS. 28 IN. VACUUM
A VACUUM CORRECTION CURVE
B PRESS. CORRECTION CURVE
C SUPERHEAT CORRECTION CURVE
LB. STEAM PER KW-HR. CONSUMPTION
SUPERHEAT DEG. F.
VACUUM IN. OF MERCURY

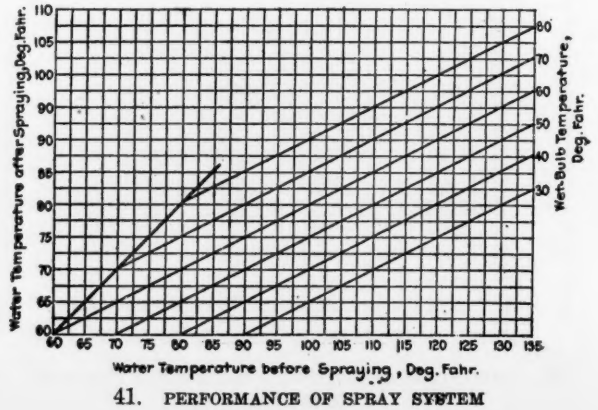
37. TYPICAL CORRECTION CURVES FOR STEAM TURBINE, 125 KW. AT FULL LOAD



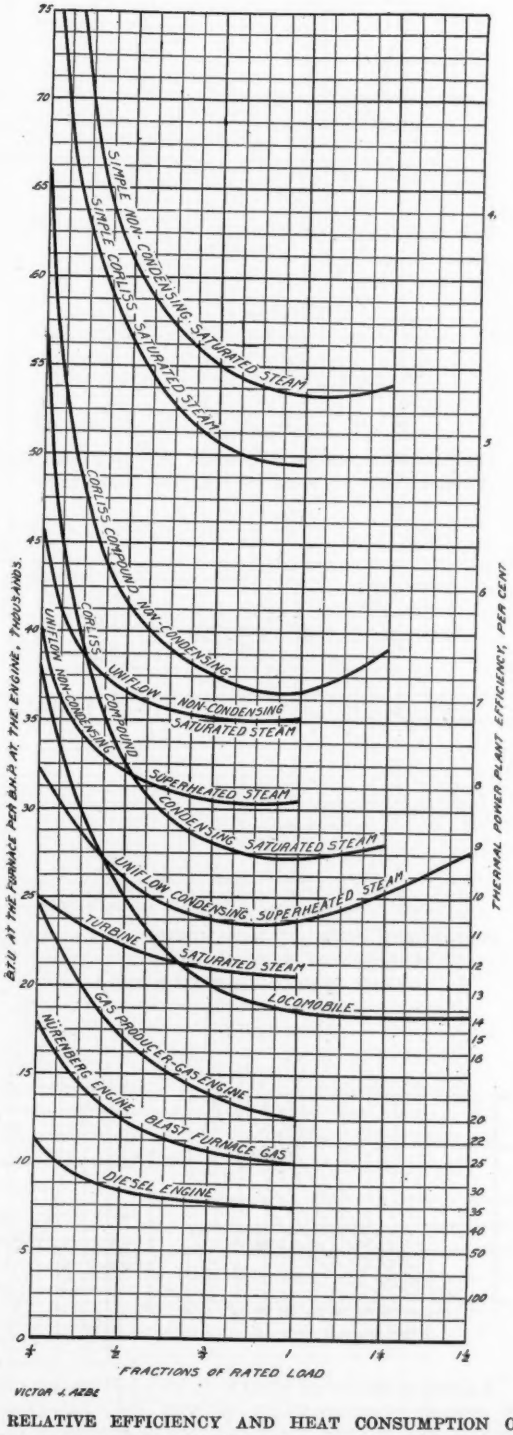
40. EFFECT OF SUPERHEAT ON STEAM CONSUMPTION OF STEAM ENGINES—GEBHARDT



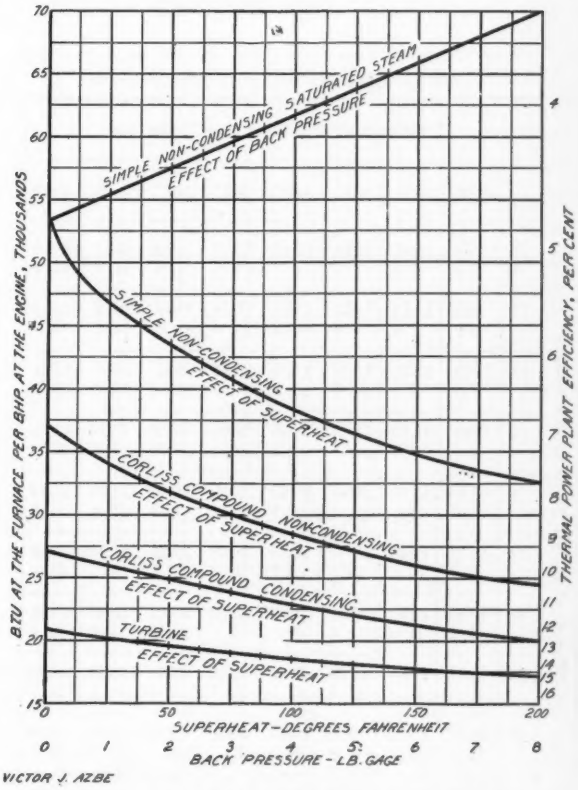
38. INFLUENCE OF VACUUM ON STEAM CONSUMPTION OF TURBINES



41. PERFORMANCE OF SPRAY SYSTEM



42. RELATIVE EFFICIENCY AND HEAT CONSUMPTION OF VARIOUS POWER INSTALLATIONS BASED ON ASSUMPTION OF 70 PER CENT EFFICIENCY, 3 PER CENT FOR BOILER FEED PUMP; 5 PER CENT FOR AUXILIARY STEAM FOR CONDENSING ENGINES, FEED WATER TEMPERATURE 200 DEG. F. HEATED BY EXHAUST STEAM OR ECONOMIZER



43. EFFECT OF SUPERHEAT OR BACK PRESSURE ON POWER PLANT EFFICIENCY

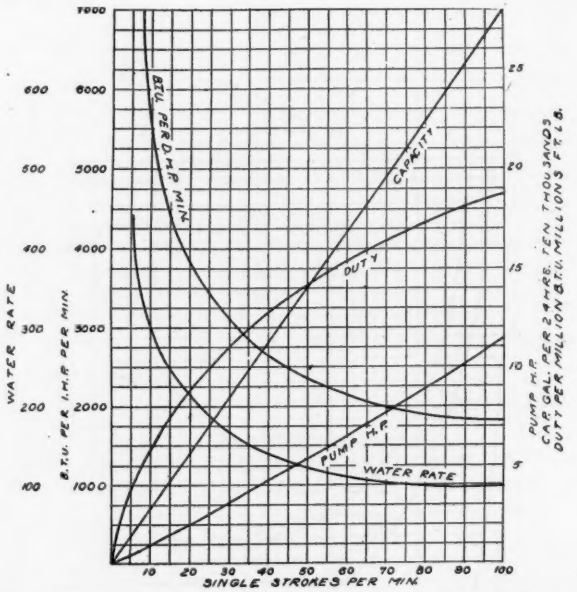
44. LOSS DUE TO INCOMPLETE COMBUSTION OF CARBON TO CO—GEBHARDT

Per Cent of CO in the Flue Gas by Volume.	Per Cent of CO_2 in the Flue Gas by Volume.					
	6	8	10	12	14	16
0 2	**328** 2 2	**248** 1.7	**199** 1 3	**168** 1 1	**144** 1	**126** 0.8
0 4	**635** 4.3	**484** 3.3	**390** 2.6	**327** 2 2	**282** 1.9	**248** 1.7
0.6	**925** 6.3	**709** 4.8	**575** 3 9	**474** 3 2	**417** 2.8	**367** 2.5
0.8	**1192** 8.1	**923** 6.3	**750** 5.1	**635** 4.3	**549** 3.7	**495** 3.4
1 0	**1494** 10.2	**1128** 7 7	**923** 6 3	**780** 5.3	**676** 4.6	**596** 4.1
1.2	**1690** 11.5	**1321** 9	**1085** 7.4	**923** 6.3	**801** 5.4	**708** 4.8
1 4	**1920** 13 1	**1512** 10.3	**1248** 8.5	**1061** 7.2	**924** 6.3	**819** 5.6
1 6	**2104** 14 3	**1693** 11.5	**1400** 9.5	**1193** 8.1	**1040** 7.1	**924** 6.3
1.8	**2340** 16	**1865** 12.7	**1549** 10.5	**1321** 9.0	**1151** 7.8	**1025** 7
2 0	**2537** 17.2	**2030** 13.8	**1690** 11.5	**1450** 9 9	**1270** 8 6	**1129** 7.7

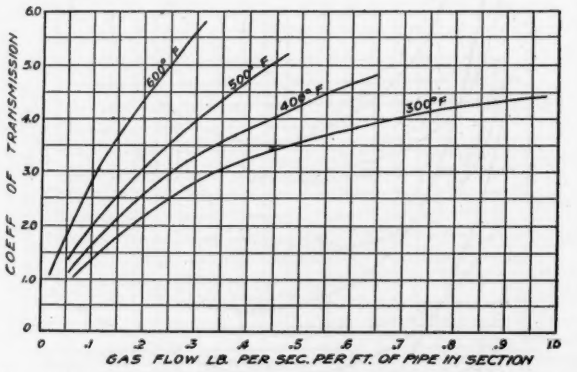
Large type gives the loss in B.T.U. per pound of combustible. Small type gives the per cent loss, assuming a calorific value of 14,650 B.T.U. per pound of combustible.

45. HEAT CARRIED AWAY BY DRY CHIMNEY GASES PER POUND COMBUSTIBLE—GEBHARDT

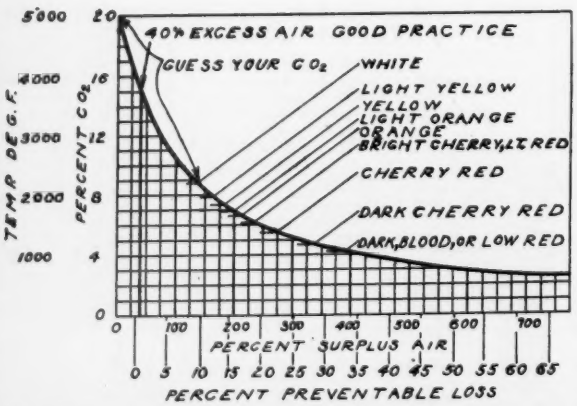
Pounds of Air per Pound of Combustible.	Temperature of Chimney Gases. Deg. Fahr.							
	300°	350°	400°	450°	500°	550°	600°	650°
12	750	905	1060	1216	1370	1528	1683	1840
*	5.2	6 2	7.3	8.7	9.5	10 5	11.6	12.7
15	865	1112	1305	1498	1679	1880	2072	2262
	6	7.6	9 1	10.3	11 6	13 0	14 3	15.6
18	1004	1321	1550	1778	2010	2235	2460	2692
	7.2	9 1	10 7	12.2	13 9	15 4	17	17.9
21	1266	1530	1785	2060	2320	2582	2846	3118
	8.7	10.5	12 3	14 2	16	17.8	19 5	21
24	1440	1740	2040	2340	2640	2940	3240	3540
	9 9	12	14	16 1	18.2	20.3	22 4	24.4
27	1611	1950	2281	2620	2958	3291	3628	3962
	11.1	13 5	15 7	18 1	20 4	22 7	25	27.4
30	1785	2160	2530	2900	3270	3641	4016	4396
	12 4	14 9	17 4	20	22 6	25	27.8	30 4
33	1957	2362	2779	3180	3589	4000	4405	4820
	13 5	16 3	19 2	22	24 7	27 6	30 5	33.2
36	2130	2579	3020	3461	3910	4350	4798	5290
	14 7	17 8	20 8	23 9	27	30	33	36.6
39	2300	2781	3261	3743	4220	4700	5180	5670
	15 9	19 2	22 5	25 8	29 2	32 4	35 7	39
42	2479	2999	3508	4023	4540	5052	5570	6100
	17 1	20 6	24 7	27 7	31 3	34 8	39 4	42



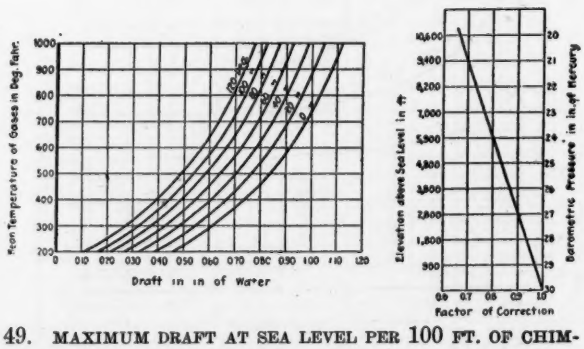
47. TYPICAL PERFORMANCE CURVES FOR DUPLEX BOILER FEED PUMPS AT VARIOUS SPEEDS—GEBHARDT



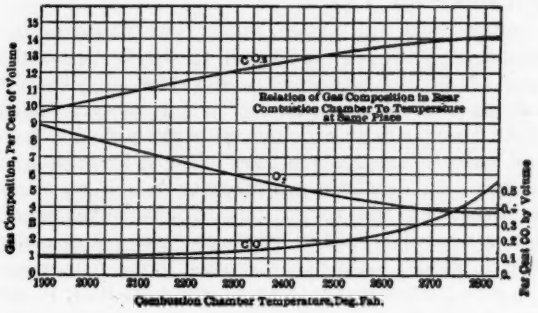
48. COEFFICIENT OF HEAT TRANSMISSION IN ECONOMIZER, AS AFFECTED BY RATE OF GAS FLOW AND MEAN TEMPERATURE OF GASES



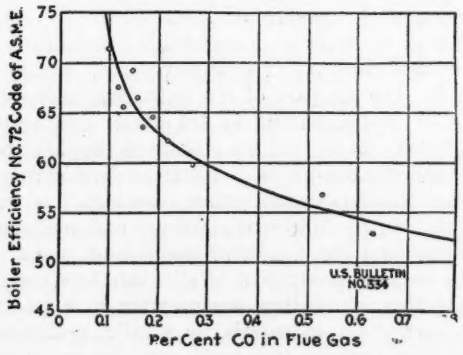
46. RELATION OF CO_2 TO SURPLUS AIR AND PER CENT PREVENTABLE LOSS AND COLOR OF FLAME AT VARIOUS TEMPERATURES OF FURNACE GASES



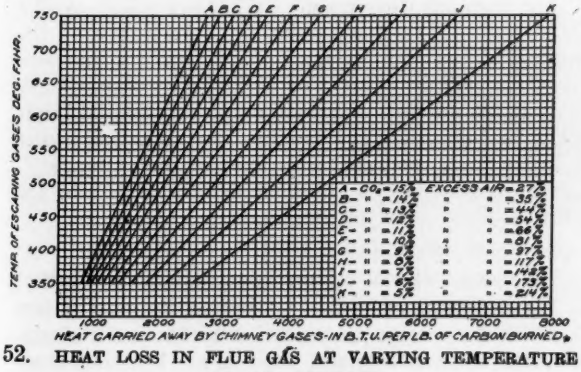
49. MAXIMUM DRAFT AT SEA LEVEL PER 100 FT. OF CHIMNEY HEIGHT CORRESPONDING TO THE AIR TEMPERATURE NOTED ON THE CURVES. FOR ANY OTHER HEIGHT H IN FT. MULTIPLY BY 0.01H. FOR ANY OTHER ALTITUDE OR BAROMETRIC PRESSURE, MULTIPLY BY THE CORRESPONDING FACTOR OF CORRECTION FROM THE CURVE ON THE RIGHT—A. L. MENZIN


Relation of Gas Composition in Rear Combustion Chamber To Temperature at Same Place
Gas Composition, Per Cent of Volume
Per Cent CO by Volume
Combustion Chamber Temperature, Deg. Fah.

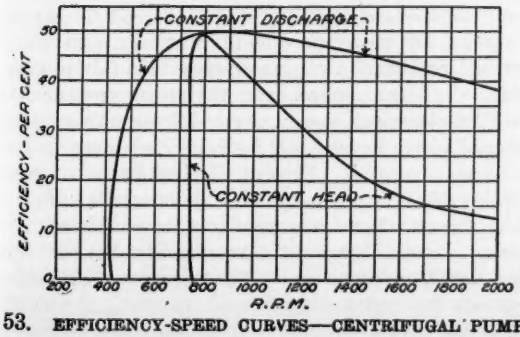
50. RELATION OF TEMPERATURE IN FURNACE TO GAS COMPOSITION



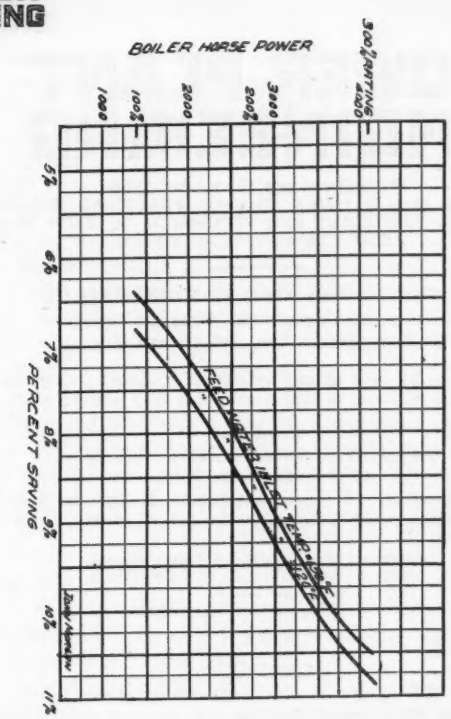
51. RELATION OF AVERAGE CO TO BOILER EFFICIENCY



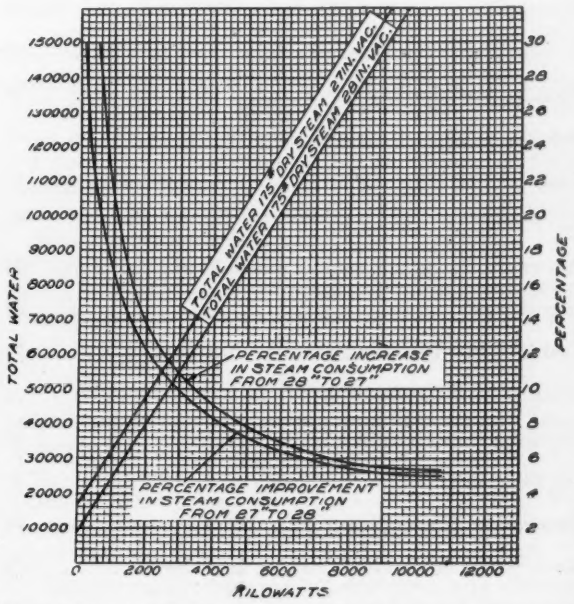
52. HEAT LOSS IN FLUE GAS AT VARYING TEMPERATURE AND CO_2 CONTENT



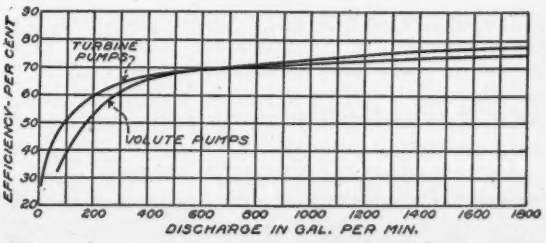
53. EFFICIENCY-SPEED CURVES—CENTRIFUGAL PUMPS



54. PER CENT FUEL SAVED DUE TO ECONOMIZER INSTALLATION


TOTAL WATER
PERCENTAGE
KILOWATTS
TOTAL WATER 1.5" DRY STEAM 27 IN. VAC.
TOTAL WATER 1.5" DRY STEAM 28 IN. VAC.
PERCENTAGE INCREASE IN STEAM CONSUMPTION FROM 28 "TO 27"
PERCENTAGE IMPROVEMENT IN STEAM CONSUMPTION FROM 27 "TO 28"

55. EFFECTS OF INCREASING VACUUM ON STEAM CONSUMPTION OF A 9000 KW. TURBINE



56. EFFICIENCY—CAPACITY CURVES FOR CENTRIFUGAL PUMPS

POWER PLANT ENGINEERING

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Our Hopes for 1920

Another year has passed and, as we pause at the threshold of 1920, we are forced to wonder what the coming 12 months may hold in store for us. True it is that the greatest armed conflict of nations ever staged has been brought to an end; but, as in the period following all wars, so has this one been followed by industrial upheavals and economic disturbances which at times have threatened the very vitals of our Government. Under irresponsible, almost irrational leadership, many have been blindly led to throw caution to the four winds and to prepare themselves to wreck the State itself in the intent of their leaders to follow the course laid by radicalism. Happily, however, the more conservative and liberal minded have begun to recognize the folly of this course and the need of the world for more constructive thought and action in place of the tearing down and destruction of our established institutions.

But mere recognition of the need is insufficient. How may we individually and collectively as a nation meet this need? On the part of the individual there should be a fuller understanding of his duties and responsibilities to his country and his fellowmen, the banishment of the individualistic idea, a better understanding that democracy involves duties rather than rights, a realization of the responsibilities of employer and employe, one to the other, and last, but by no means least, unrestricted effort to increase production of all kinds to a maximum and reduction of needless consumption to a minimum. On the part of the industries, by a fuller realization of the fact that business is a great, exciting and interest-absorbing game and that only by allowing each worker to participate as a player, can loyalty and contentment be attained.

And then our Government. What can it do? Above all, it can and must recognize the sovereignty of the people and must not, as some of our recent Congresses have done, be led by threat or intimidation to pass legislation in the interests of greedy politicians, special interests, religious zealots and fanatics and organized bodies of individuals working and existing only for self-aggrandizement, all to the hurt and detriment to the great majority—the public.

Such are our hopes for 1920.

How long will coal remain a commercial commodity?

We do not know. We do, however, realize the fact that with the present per cent of annual increase of consumption our available coal deposits are becoming more and more inaccessible and, as a consequence, coal will not only become scarcer, but is bound to increase in price. Eventually, in order to provide an adequate supply for domestic use, industry will be forced to employ other means for power-producing purposes, and while the internal combustion engine already bids fair to compete with the steam engine and the steam turbine, we believe that electrical energy derived from our existing but unused water powers will be depended upon to run our mills and factories. Present Federal laws, however, place navigable streams under War Department jurisdiction and cannot, therefore, except under conditions uninviting to capital for such developments, be used for power production purposes. This leaves available only streams not deemed navigable and, as the majority of these at best could provide but a limited amount of

power, little headway may be expected in this direction until pending legislation is passed, providing for the use of navigable streams for this purpose. In fact, all obstacles in any way interfering with the development of our water powers should without hesitancy be removed and thereby assist in relieving a situation growing daily more acute. Delay is fraught with danger, for, according to no less an authority than Dr. C. P. Steinmetz, even though all of our available water power should be developed for electrical energy generation, this would be but one-fourth of that at present produced by the coal consumed. It is therefore imperative that Congress take early action not only to remove existing restrictions, but also to pass such legislation as will make attractive the investment of capital in such developments.

Such are our hopes for 1920.

Another year has passed and with regret we note that the engineer has done but little to bring himself into his rightful place in governmental affairs and executive position. Too engrossed in his work, he finds but little time to participate even to a limited extent either in politics or civic affairs and as a result, except in a professional way, he is of but little service to society.

Now again, as in an editorial appearing in an early issue of 1919, we urge that in the future engineers should be as frequent and as prominent as lawyers, doctors or business men on public committees and in public office. This can be accomplished if each engineer will but get outside of his rut—make the most of himself as a man—and then co-operate with his fellow engineers to see that those fitted by natural endowment and attainments for high leadership are given the recognition and positions that they deserve.

And such are our hopes for 1920.

This Issue

Among the interesting facts brought to light by the work of the Fuel Administration a year ago was the lack of definite information possessed by power plant owners in general throughout the country relative to the operation and condition of their plants. Many of these owners were awakened to their needs of such information by the requirements of the Fuel Administration and in their endeavor to collect the proper information and use it to best advantage, have called upon the editors of POWER PLANT ENGINEERING for assistance in planning the records, directions for using the data collected and suggestions regarding selection of instruments to be installed.

So numerous were these requests and so inadequate are many of the forms now in use that this issue was planned and has been prepared to give the reader definite instructions for planning his own records, which is, after all, an individual problem in each plant. Not only directions for planning but for using the data collected are outlined which is far more important than the mere collection of records to be filed away and discarded when the space in which they are stored is needed for some other purpose.

The study which has been given the subject indicates that in the large majority of cases where records are in use the demand for such has come from the owner and not, as an engineer would like to think, from the desire of the engineer to improve the operation of his plant. Any log sheet will show whether or not it is planned by a man well up in the science of power plant operation or by the man responsible for the financial success of the plant. The majority of records have been found to be of the latter type which certainly is not to the credit of the engineer in charge of such plants.

To know costs is essential, but to reduce them is the work of the engineer and this can be done only by careful and continuous study of operating conditions which is aided by arranging the data necessary for this study in such a way that it can be compared easily and readily and its influence on the rest of the plant indicated. This constitutes analysis as the term is used throughout the issue.

The issue does not stop with directions for collecting and analyzing cost and operating data, but includes a section on tests and an investigation of plant needs. These are important and show uses for material collected on daily sheets which in many plants is thought useless.

Nearly all data collected are instrument readings, it is of importance that these be carefully chosen for the purpose to which they are to be put and the reader will find help in making the proper selection by reference to this section of the issue.

Realizing that the analysis of operating data may consume an endless amount of time if the engineer is not prepared for the task with charts and tables, a large section of the paper is devoted to such information applicable in a general way to all steam plants.

In presenting this issue the editors have used information gleaned from numerous sources, principally the excellent handbook of Gillette and Dana on Mechanical and Electrical Cost Data, the proceedings of the American Society of Mechanical Engineers, Gebhardt's book on steam power plant engineering and Moyer's work on power plant testing, to these acknowledgment is given here as it has not been possible to give credit in all places where the selected information was presented. Our gratitude is also extended to manufacturers of instruments who have aided in presenting the typical descriptions presented in this issue.

WHETHER or not the internal combustion type of engine will ever supersede the steam engine as a prime mover remains to be seen. The fact is that every year greater numbers of oil engines of the Diesel and semi-Diesel type are being turned out than ever before. This causes an increasing demand for engineers who understand and can operate these engines.

Literature, however, has not kept pace with advances made in oil engine practice, and Lacey H. Morrison's new book on oil engines will help. Its objects are to acquaint the oil engine operator with "details of construction and methods of adjustments of the most important oil engines manufactured in the United States." The first chapter is devoted to a brief history of the internal combustion engine. There are chapters on Types of Diesel Engines; Installation; Main Bearings; Connecting Rods; Valves; Pumps; Governors; Air Compressor Systems; Lubrication; Cooling; Fuels, and Fuel Consumption. Chapter 17 treats of the Semi-Diesel Engine, and the remaining nine chapters are devoted to low compression types of oil engines.

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TRADE NEWS

IT IS ANNOUNCED that negotiations have been completed whereby Jenkins Bros. will, in the near future, increase its manufacturing facilities, by owning and operating a plant in Bridgeport, Conn. This plant will be devoted entirely to the manufacture of the Jenkins valve—an engineering product which dates back to 1865, when Nathaniel Jenkins invented and first introduced the renewable disc type of valve.

The heirs of the founder of the business continue to hold the controlling interest in the company, thus insuring the standard of quality which has ever been their endeavor to maintain. The present head of the company is Farnham Yardley, a son-in-law of the late Alfred B. Jenkins. Frank T. Swain, who has been connected with Jenkins Bros. since 1879, is vice-president, and it is expected that Charles V. Barrington, who has a wide experience in the manufacture of valves, will also be elected a vice-president of the company, and will be in charge of the Bridgeport plant.

The manufacture of the Jenkins discs, sheet packings, pump valves and other mechanical rubber goods, will be continued at Elizabeth, N. J.

To take care of the rapidly increasing business in Jenkins valves abroad, the Canadian branch, Jenkins Bros. Limited, of Montreal, has recently completed and now has in course of construction a new 192 by 80-ft. iron valve foundry. The Canadian branch supplies alterations and additions to its brass valve department, Jenkins valves throughout Canada and foreign countries, while the Bridgeport plant will make valves for use in the United States and insular possessions.

THE HOOVEN, OWENS, RENTSCHLER CO., of Hamilton, Ohio, has opened two new offices and has made one or two changes in the personnel of its offices, as follows: A new office has been opened in Philadelphia, and C. M. Decker, formerly with R. D. Wood Co., has been made manager. The office is located at 2129 Land Title Building. A new office has also been opened at Richmond, Va., with E. H. Fairchild, formerly of the C. & G. Cooper Co., in charge. E. S. Cooley, formerly with the Fall River Ship Building Co., is now connected with the New York office of the Hooven, Owens, Rentschler Co. Henry E. Balsley, formerly with the American Bridge Co., has been made manager of the Chicago office. R. C. Holman, formerly with the General Electric Co., Centrifugal Department, is now associated with the Hooven, Owens, Rentschler Co., in charge of all blowing engines.

MIDWEST ENGINE CO. held its annual sales convention in Indianapolis and Anderson, Ind., from Dec. 2 to 6, inclusive. One interesting point brought out was that during the war the firm had built several hundred Diesel engines for submarines and submarine chasers.

A test was conducted on a 10-stage tandem turbine driven mine pump, built to operate against a 1400-ft. head (606 lb.). This pump will be used in a Western mine and is said to be only the second pump ever built to work against so great a head.

THE STAR BRASS WORKS, Chicago, Ill., has recently issued a new 12-page bulletin, No. 6, pertaining to the company's line of small steam and water jet apparatus, comprising steam and water syphons or ejectors, also small steam jet pumps applicable to apparatus requiring vacuum, used as centrifugal pump primers, etc., fully illustrated, also including considerable engineering data involved.

HENRY P. THOMPSON, Cincinnati, Ohio, a district representative of the American Steam Conveyor Corporation, Chicago, has added to his sales engineering staff Albert A. Casey, who will push the sale of the American steam jet conveyor in that territory. Mr. Casey is a mechanical engineer, a graduate of the Ohio State University and a valuable addition to Mr. Thompson's sales organization.

LINK-BELT CATALOGS were lately received as follows: Book No. 380, Link-Belt Electric Hoists and Overhead Cranes; Book No. 375, Link-Belt Labor-Saving Elevators and Conveyors.

AEROIL THAWING OUTFITS for thawing out frozen cars, pockets, hoppers, pipes, switches, loading gates, chutes, etc., are illustrated and described in the latest bulletin of Aeroil Burner Co., Union Hill, N. J.

A TWO-YEAR CALENDAR illustrated by halftone views of Gardner Governor Co.'s works and apparatus was recently received.